



ARL-SR-0387 • DEC 2017



US Army Research Laboratory

# **2017 ARL Summer Student Program, Volume I: Symposium Presentations**

**Compiled by Rose Pesce-Rodriguez**

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REPORT DOCUMENTATION PAGE				Form Approved OMB No. 0704-0188	
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## Director's Foreword

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The US Army Research Laboratory (ARL) mission is to “provide innovative science, technology, and analyses to enable full spectrum operations.” As the Army’s corporate laboratory, we provide the technological underpinnings critical to providing capabilities required by our current and future Soldiers.

Our nation is projected to experience a shortage of scientists and engineers. ARL recognizes the criticality of intellectual capital in generating capabilities for the Army. As the Army’s corporate laboratory, addressing the projected shortfall is a key responsibility for us. We have, therefore, identified the nation’s next generation of scientists and engineers as a key community of interest and have generated a robust educational outreach program to strengthen and support them. We have achieved many successes with this community. We believe that the breadth and depth of our outreach programs will have a significant positive effect on the participants, facilitating their journey toward becoming this Nation’s next generation of scientists and engineers.

A fundamental component of our outreach program is to provide students with summer research experiences. During the summer of 2017, ARL hosted more than 170 undergraduate and graduate students. Many of these students chose to participate in directorate-level competitions with the goal of being selected as a directorate finalist and competing at the ARL-wide Summer Student Symposium; others participated in the symposium by presenting posters. I applaud symposium participants and all summer interns who contributed to the ARL mission.

We are very pleased to have hosted this outstanding group of students for the summer. It is our hope that they will continue their pursuit of technical degrees and will someday assist us in providing critical technologies for our Soldiers.

Philip Perconti  
Director

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## Introduction

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The ARL Summer Student Research Symposium is an ARL Director's Award Program for students participating in various summer internship opportunities across ARL. The goal of the program is to recognize and publicize exceptional achievements made by the students and their mentors in the support of Army science.

All undergraduate and graduate interns are eligible to compete for a finalist position and give an oral presentation at the symposium. All students, including high schoolers in the Science and Engineering Apprentice Program (SEAP), are encouraged to present posters at the symposium and submit abstracts summarizing their accomplishments.

Oral presentations at the symposium are given by finalists selected based on directorate-level competitions. Each directorate can send one graduate student and one undergraduate finalist to the symposium. The Sensors and Electron Devices Directorate and Weapons and Materials Research Directorate have relatively large numbers of interns and can each send 2 undergrad finalists.

This year's symposium was held at the Mallette Center at Aberdeen Proving Ground, Maryland, on Thursday, 10 August 2017. Oral presentations were judged by a panel of senior ARL scientists (including ARL Fellows and Chief Scientists). Students with the top 3 presentations ("Corporate Medalists") were awarded the ARL Summer Student Research Gold (\$500), Silver (\$300), and Bronze (\$200) awards in the undergraduate and graduate student levels.

This volume of the Summer Student Symposium Proceedings contains presentations given by all directorate finalists at the symposium. Volume II (ARL-SR-0388) is a compendium of student abstracts.

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## 2017 ARL Summer Student Symposium Agenda

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10 August 2017  
Mallette Training Center Auditorium (B6008)  
Aberdeen Proving Ground, MD

<b>0700</b>	Bus departs ALC	
<b>0820</b>	Bus arrives from ALC	
<b>0830-0840</b>	Welcome	Dr. Rose Pesce-Rodriguez
<b>0840-1130</b>	<b>Undergraduate Presentations (Auditorium)</b>	
	Robust Adaptive Control of Unmanned Aerial Systems (UAS)	Blake Anderson (VTD)
	Dynamic Occlusion Culling in VR	Ben Kolarik (SLAD)
	Fabrication & Characterization of Silicon Nanoparticles for Energetic Applications	Sarah Adams (SEDD)
	Ultra-Low-Power Sensing & Processing	Peter Deaville (SEDD)
	A Comparison Study of Carbon Polymer Electrodes for Electroencephalography (EEG) Recording	Christina Nguyen (HRED)
	Collision Avoidance Robot Using Neuromorphic Hardware	Clarence Wong (CISD)
	High-Strain Rate Hardness of Tungsten Carbides	Luke Hanner (WMRD)
	Effect of B:B2O3 on Reactive Hot-Pressing of Boron Suboxide"	Howard Payne (WMRD)
<b>1130-1215</b>	Lunch + poster session (Room 10B) Deliberations (Undergrad category) by Review Panel	All
<b>1215-1420</b>	<b>Graduate Presentations (Auditorium)</b>	
	A physical Manifestation of Dynamic Scaling Laws	Daniel Blackman (VTD)
	Limits of Subpixel Motion Detection with a Video Camera	Minas Benyamin (SEDD)
	The Effect of Imperceptible Noise Stimulation on the Spinal Reflex	Maxwell Alander (HRED)
	Solving Vertex Cover Via Using Spin Model On Neuromorphic Processor	Kevin Corder (CISD)
	Modeling RDX Decomposition Products with Mesoscale Particles	James (Matt) Mansell (WMRD)
	Visualization of Human Vulnerability in VR	Tiffany Raber SLAD
<b>1420-1455</b>	Refreshments + poster session (Room 10B) Deliberations (Graduate category) by Review Panel	All
<b>1450-1515</b>	Awards Ceremony	
<b>1530</b>	Bus departs for ALC	
<b>1645</b>	Bus arrives at ALC	

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## 2017 ARL Summer Student Symposium

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### Undergraduate category winners

#### Gold Medalist:

Sarah Adams, Sensors and Electron Devices Directorate  
Fabrication & Characterization of Silicon Nanoparticles for Energetic Applications

#### Silver Medalist:

Peter Deaville, Sensors and Electron Devices Directorate,  
Ultra-Low-Power Sensing & Processing

#### Bronze Medalist:

Luke Hanner, Weapons & Materials Research Directorate,  
High-Strain Rate Hardness of Tungsten Carbides

### Graduate category winners

#### Gold Medalist:

James (Matt) Mansell, Weapons & Materials Research Directorate  
Modeling RDX Decomposition Products with Mesoscale Particles

#### Silver Medalist:

Minas Benyamin, Sensors and Electron Devices Directorate  
Limits of Subpixel Motion Detection with a Video Camera

#### Bronze Medalist:

Maxwell Alander, Human Research & Engineering Directorate  
The Effect of Imperceptible Noise Stimulation on the Spinal Reflex

Special awards were presented to 2 of the top student presentations from ARL West.

ARL West top honors for 2017 presentations:

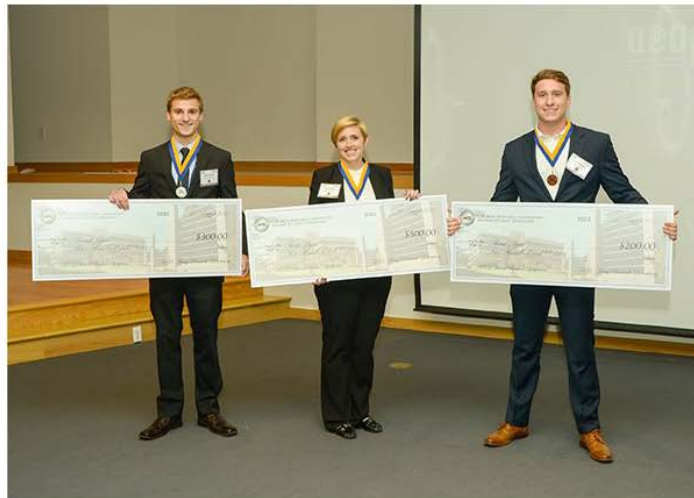
Undergraduate category: Elnaz Ahmadi, University of California, Santa Barbara

Graduate category: Tiffany Raber, University of Illinois at Chicago



Undergraduate and graduate Directorate Finalists who participated in the U.S. Army Research Laboratory's 2017 Summer Student Symposium held August 10 at Aberdeen Proving Ground, Maryland. (U.S. Army photo by Conrad Johnson, RDECOM).

<https://arlininside.arl.army.mil/inside/news/articles/view.cfm?id=2051>



The undergraduate Gold Medalist, Sarah Adams; Silver Medalist, Peter Deaville and Bronze Medalist, Luke Hanner display their winnings from the U.S. Army Research Laboratory's 2017 Summer Student Symposium held August 10 at Aberdeen Proving Ground, Maryland. (U.S. Army photo by Conrad Johnson)

<https://arlininside.arl.army.mil/inside/news/articles/view.cfm?id=2051>



The graduate Gold Medalist, James (Matt) Mansell; Silver Medalist, Minas Benyamin and Bronze Medalist, Maxwell Alander display their winnings from the U.S. Army Research Laboratory's 2017 Summer Student Symposium held August 10 at Aberdeen Proving Ground, Maryland. (U.S. Army photo by Conrad Johnson, U.S. RDECOM)

<https://arlinside.arl.army.mil/inside/news/articles/view.cfm?id=2051>

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## **Undergraduate Presentations**

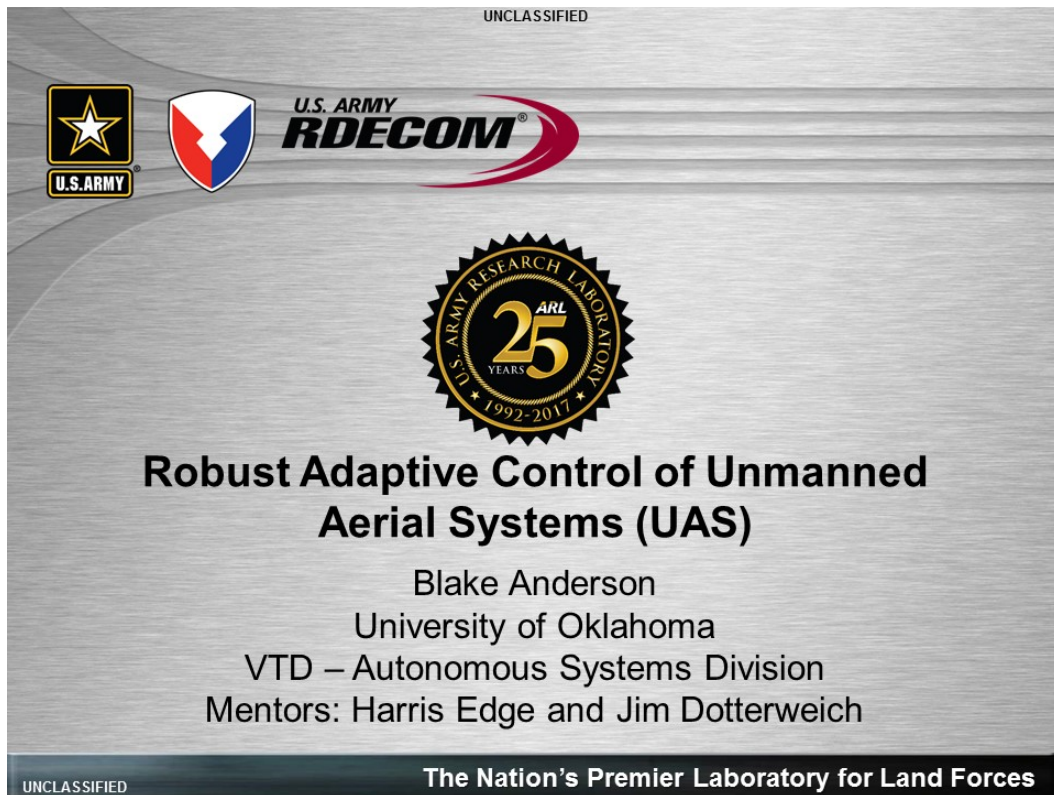
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## Blake Anderson

I am currently a senior attending the University of Oklahoma (OU). My major is engineering physics with a design sequence focusing on aerospace engineering; more specifically, I am focusing on the controls side of aerospace. I began doing research at the Advanced Control Systems Lab (ASCL) at OU in May of 2016. At ASCL, we have been focusing on creating easy-to-use interfaces for control testing and accurate virtual simulators, as well as designing autopilots with nonlinear controls for multirotor vehicles. My current advisor, Dr Andrea L'Afflito, runs ASCL, and after graduating this December, I plan on pursuing my master's degree in aerospace engineering under his guidance.



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## Problem Statement

**Controls research focusing on allowing drones to do work in an unstructured environment**

- **Environmental Interaction**
  - Perching
  - External factors (wind, rain, etc.)
  - Payload Manipulation (swinging payloads)
- **New problems**
  - Changing mass
  - Dynamic payloads
  - Surface interaction

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## Technical Approach

- Design and implement a robust adaptive controller for a quadrotor vehicle
- Created a new methodology:
  - Created reliable virtual simulator for testing & performance prediction
  - Odroid single board computer connected to a Pixhawk autopilot running the open source PX4 flight stack.

MK-82 JDAM

- Gen I: flown 1999, 2003
- Gen II: 2002 – 2006
- ✓ flight test 4th Q 2005
- Gen III: 2006

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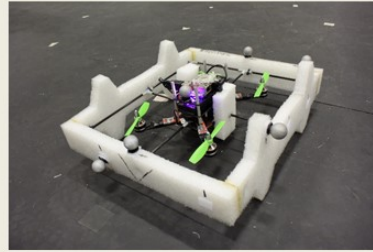
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Impact

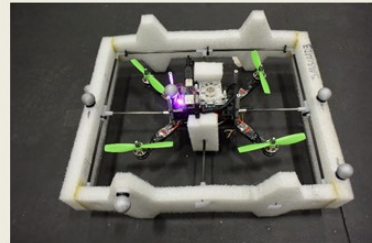
ARL



- **Advanced control techniques** that guarantee **robustness** to strong external **disturbances**, **failures** of the propulsion system, & high **safety margins**.



- **Rapid development** of new **control algorithms** by streamlining the transition between control design, simulation, & experiments.



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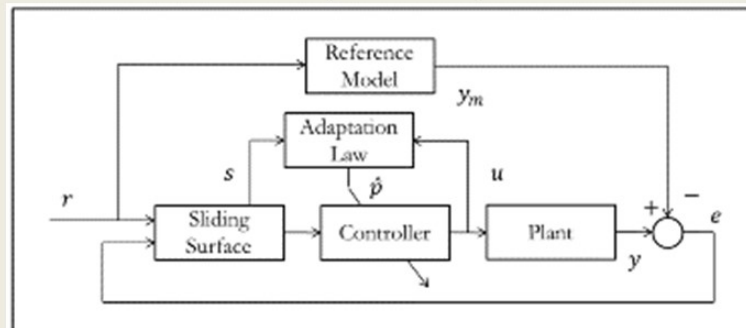
Control Approach

ARL



## Adaptive Sliding Mode

- Gains are now **functions of time**
  - Classic PID gains are fixed
- Corrects for **uncertainties** the system
  - Different masses, inertias, or even actuator faults





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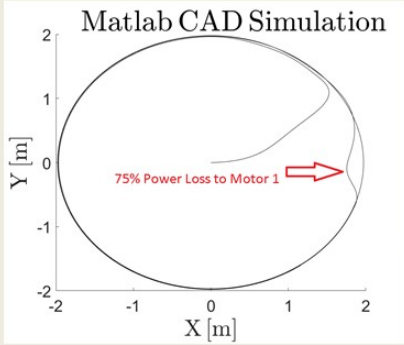
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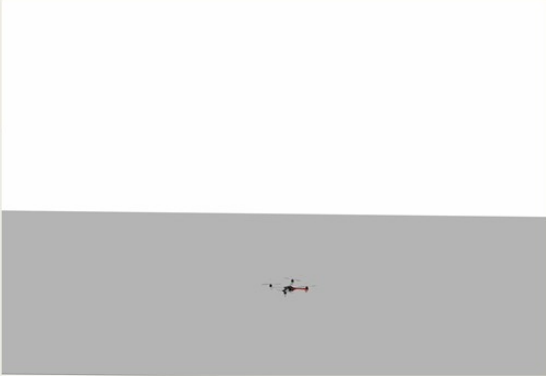
## Results I

### MATLAB CAD Simulation

- Trajectory can still be followed after **a loss of 75%** in the thrust of one of the motors.







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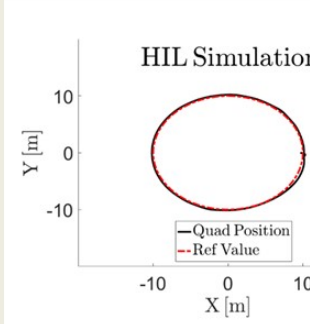
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## Results II

### Hardware in the Loop Simulation

- HIL simulation executes the exact **same code structure** that runs in real flight.
- **Reduced risks & better use flight test time**
- Uses QGroundControl





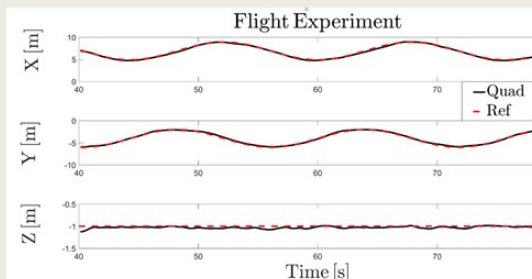
Chosen simulator: jMAVSim

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## Waypoint and Trajectory Following



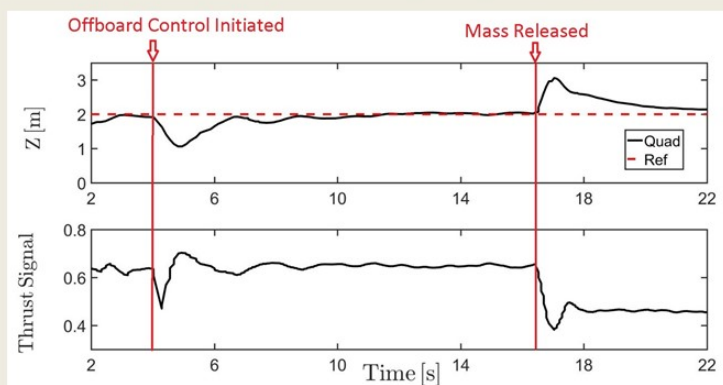
Flight test results showing the quad following circle of **2 m radius** at constant altitude

Avg error in x-y < 9 cm

Avg error in z < 3 cm

8

## Changing Payload



Mass of the vehicle is changed approximately **40%**

- Correction occurs in **under 3 s**
- Controller tuned for and assumes mass of .91 kg, actual mass = 1.4 kg

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## PID



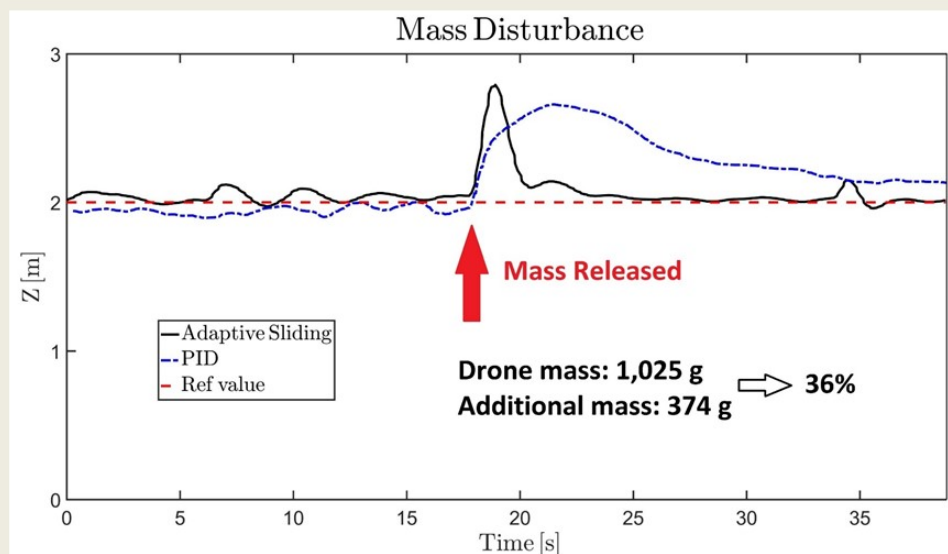
Much **slower response** to disturbance

## Adaptive Sliding Mode



Returns to desired height in under **3 s**

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- ✓ Successful **virtual, hardware-in-the-loop, and indoor tests** for proposed control algorithm.
- ✓ Shown **higher performance** with respect to classical PID-based autopilots.
- ✓ Successfully demonstrated **disturbance rejection** with changing mass.

### Near Future Work

- More **indoor and outdoor tests**.
- Matching simulation and test results.
- Carrying **dynamic payload**.

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### ARL Collaboration with University of Oklahoma

- **Open Campus** -- Discussions with ASD
- Signed a **CRADA** -- Joined **ARL South**
- Taking the **same vehicle** to test in a similar **Vicon system**

OU





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## Acknowledgements

**Special thanks to:**

- Mentors Harris Edge and Jim Dotterweich
- VTD and the Autonomous Systems Division
- Advisor Dr. Andrea L'Afflitto





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## Questions?

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1. Wang, Lifeng, Chongkui He, and Pei Zhu. "Adaptive sliding mode control for quadrotor aerial robot with I type configuration." *International Journal of Automation and Control Engineering* (2014).
2. Gregory, Irene. "Fundamentals of Adaptive Control: Flight Control Perspective," NESC GNC Webcast, 28 November 2012.

## Benjamin Kolarik

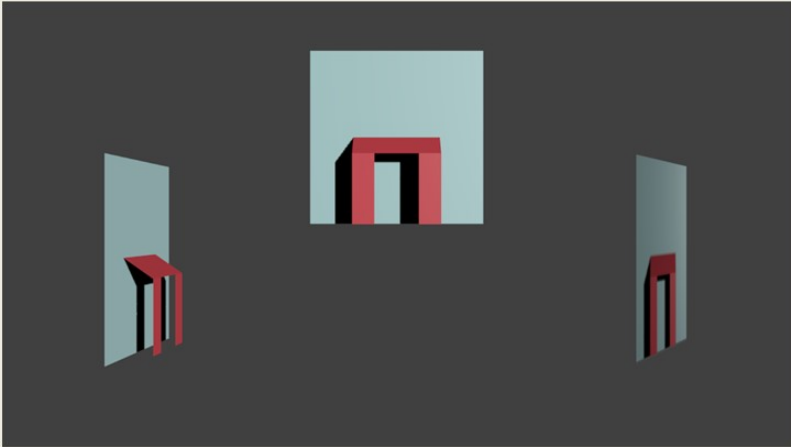
I am a senior undergraduate student in computer science at the University of Maryland, Baltimore County in Catonsville, MD. This is my first summer in the ARL internship program. After graduating I hope to work in the field of computer graphics, either with ARL or in the private sector.

I would like to thank my mentors for their assistance in this work, as it would not have been possible without them. This summer has improved my knowledge in the field of computer graphics as well as given me workplace experience.



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## Issues with vehicle geometry in VR



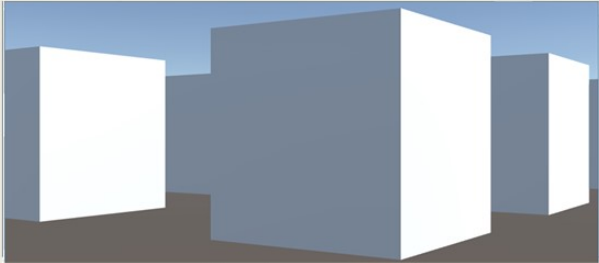
Some game engines are designed to work well with VR. However, the texture optimization that most products produced on these engines uses cannot be used for vehicle analysis.

2

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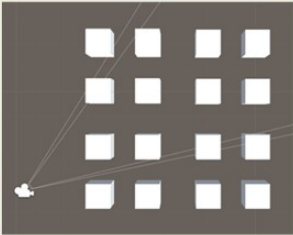
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## Occlusion culling explanation

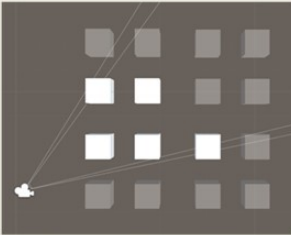


View from camera

- Rays are fired from a camera.
- Objects that rays collide with are made visible.
- Objects that do not have rays collide with them fire rays back.
- If those rays are blocked, the object is not displayed.



Complete scene




Scene with occluded cubes culled

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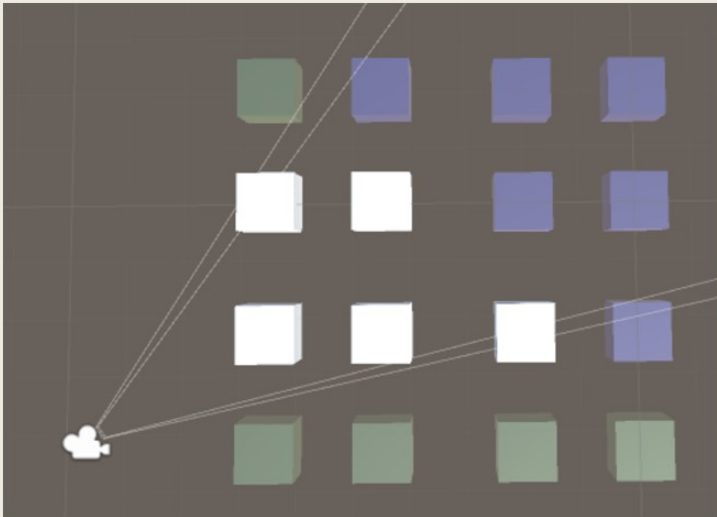
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Occlusion culling explanation cont.





Blue cubes aren't rendered because they are blocked, or occluded by other cubes.


Green cubes aren't rendered because they are outside of the viewing frustum.

White cubes are rendered.

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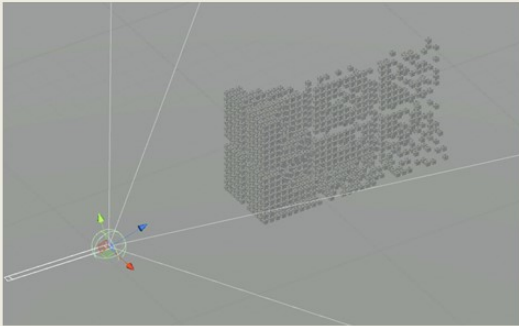
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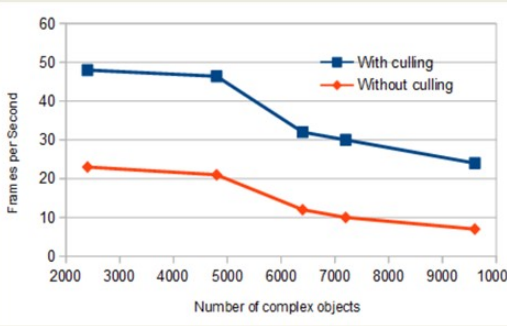


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Occlusion culling doubles performance







Number of complex objects	With culling (FPS)	Without culling (FPS)
2000	48	22
4000	47	21
6000	32	12
8000	30	10
9500	24	8





This test case we developed simulates complex geometry using over 4000 Menger sponges, which is an appropriate approximation of the geometry ARL uses.

When occlusion culling is used, performance increases due to the decreased number of objects that need to be shown.

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Menu for visibility







Analysts often need to see parts of geometry that are inside the vehicle.  
This menu allows them to view that geometry.

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Future additions



- Introduction of a cutting plane, to improve ease of analysis
- Refinement of menu system, needs more ways to select visible objects
- Informing user of the name of the viewed part, so that analysts understand what items they are looking at

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Questions

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???

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## Sarah Adams

Sarah Adams is a senior majoring in materials science and engineering at the University of Maryland. This summer her research covered the fabrication and combustion of silicon nanoparticles made from porous silicon films. Sarah previously worked in the Center for Nanophysics & Advanced Materials at the University of Maryland, studying the effects of lanthanide superconductor doping and the application of the Kondo insulator  $\text{SmB}_6$  as a driver for self-oscillating circuits. She will graduate in December of this year, at which point she plans to enter the workforce prior to returning to school to complete a master's degree.

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### Fabrication & Characterization of Silicon Nanoparticles for Energetic Applications

Sarah K. Adams, [sarah.k.adams8.ctr@mail.mil](mailto:sarah.k.adams8.ctr@mail.mil)  
Mentor: Nicholas Piekiet, [nicholas.w.piekiet.civ@mail.mil](mailto:nicholas.w.piekiet.civ@mail.mil)

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## Background

### On-chip Energetics

Advanced electronics/MEMS capabilities

**Army Applications:**

- Microthrusters
- Thermal battery actuation (FY17-19 ManTech)
- Fuzing

**Desired Properties:**

- ✓ High energy density
- ✓ High power density
- ✓ Inexpensive

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## Porous Silicon

- PSi films well-studied for energetic properties
  - Tunable flame speeds: 1 m/s to 3000 m/s
  - High surface area (>800 m<sup>2</sup>/g), hydrogen-terminated surface
- Reacts well with NaClO<sub>4</sub>

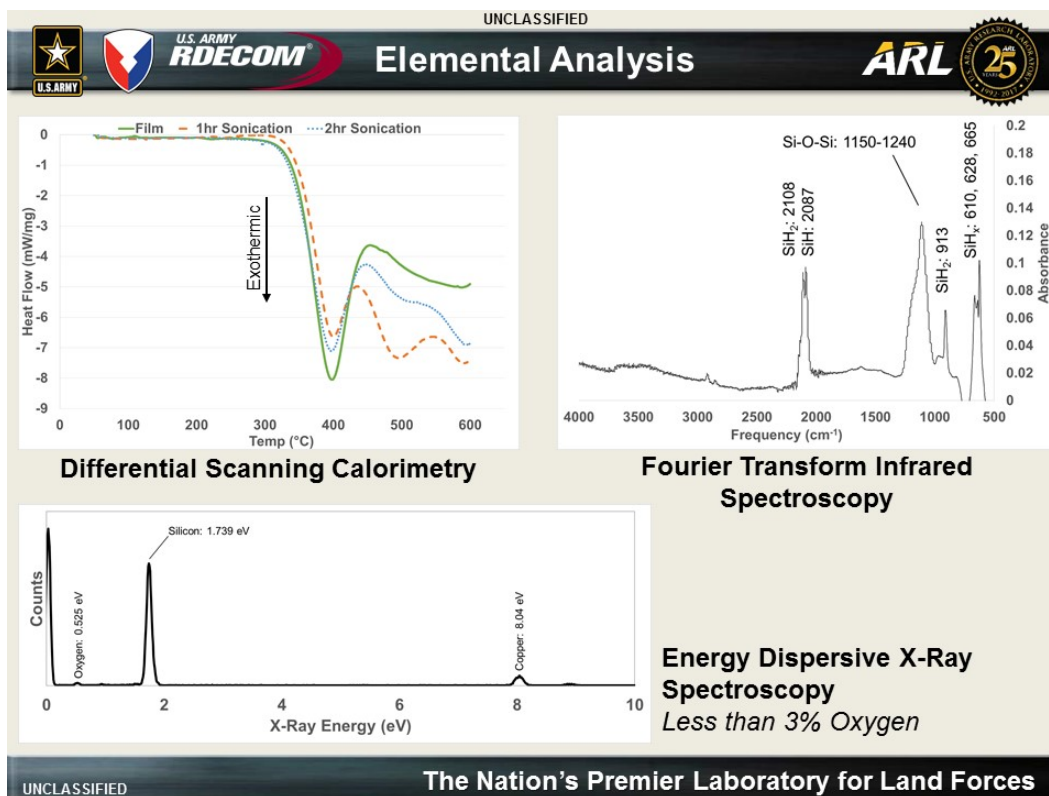
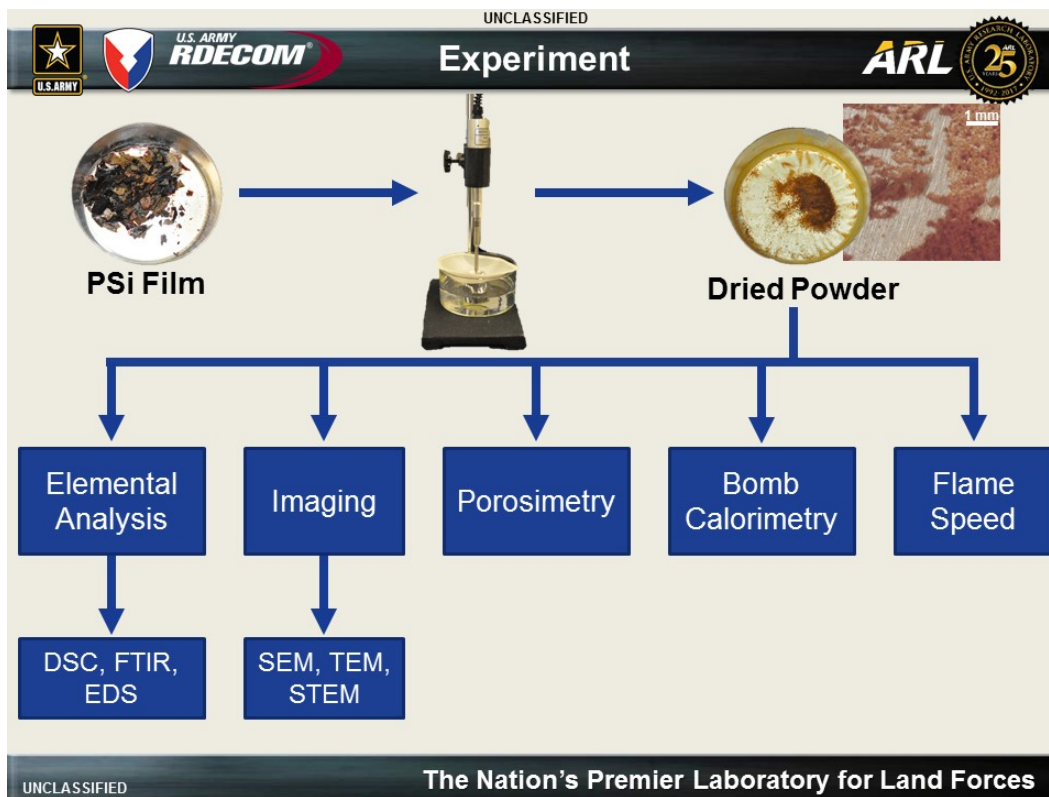
$$(1 - n)\text{Si} + n\text{SiH}_2 + \frac{2 + n}{4} \text{NaClO}_4 \rightarrow \text{SiO}_2 + \text{NaCl} + n\text{H}_2\text{O}$$
- Formed by electrochemical etch in HF → **Limited applications**

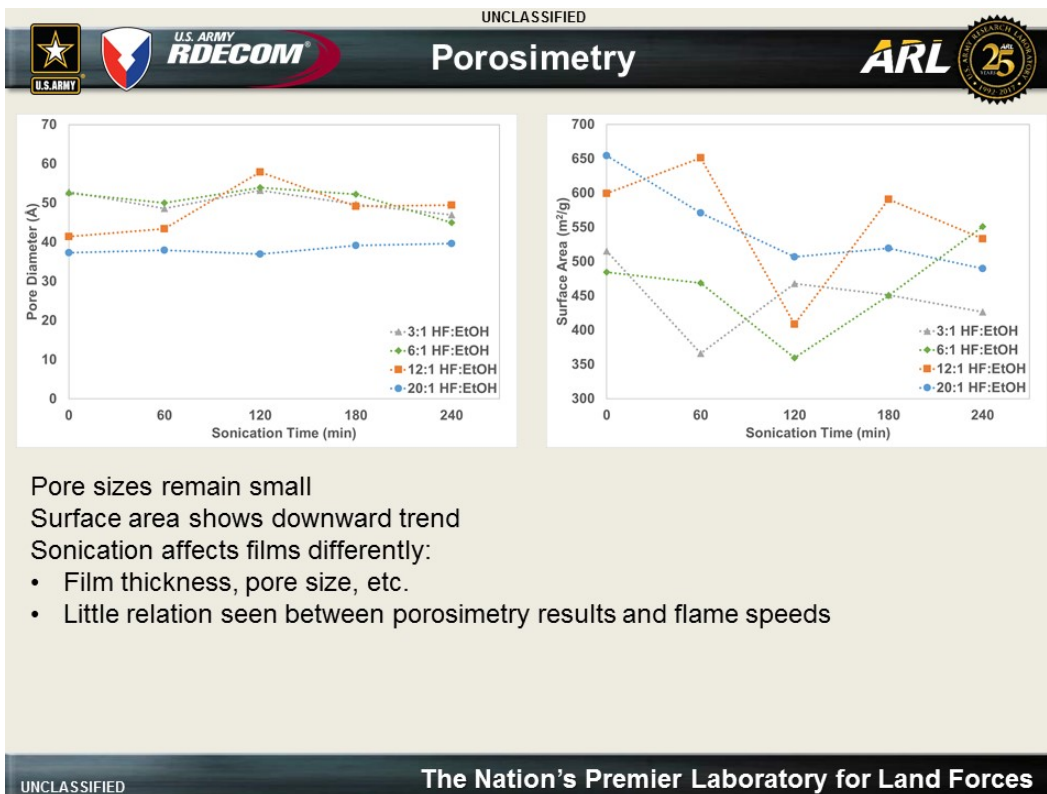
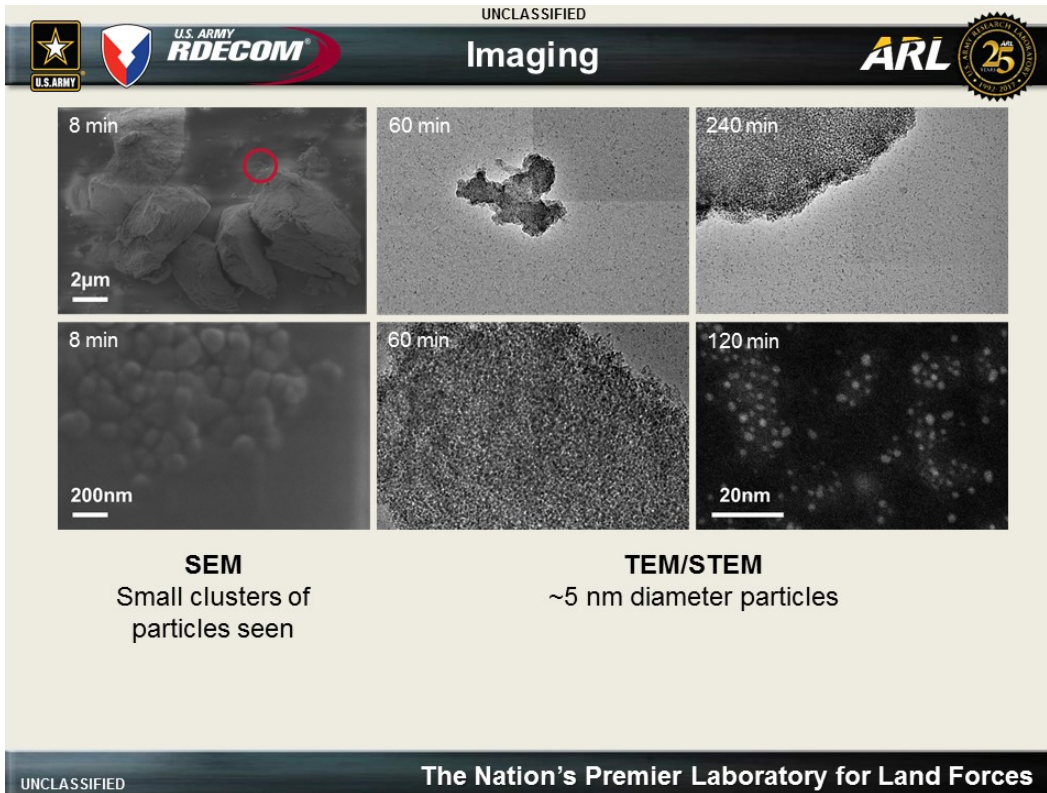
**Goals**

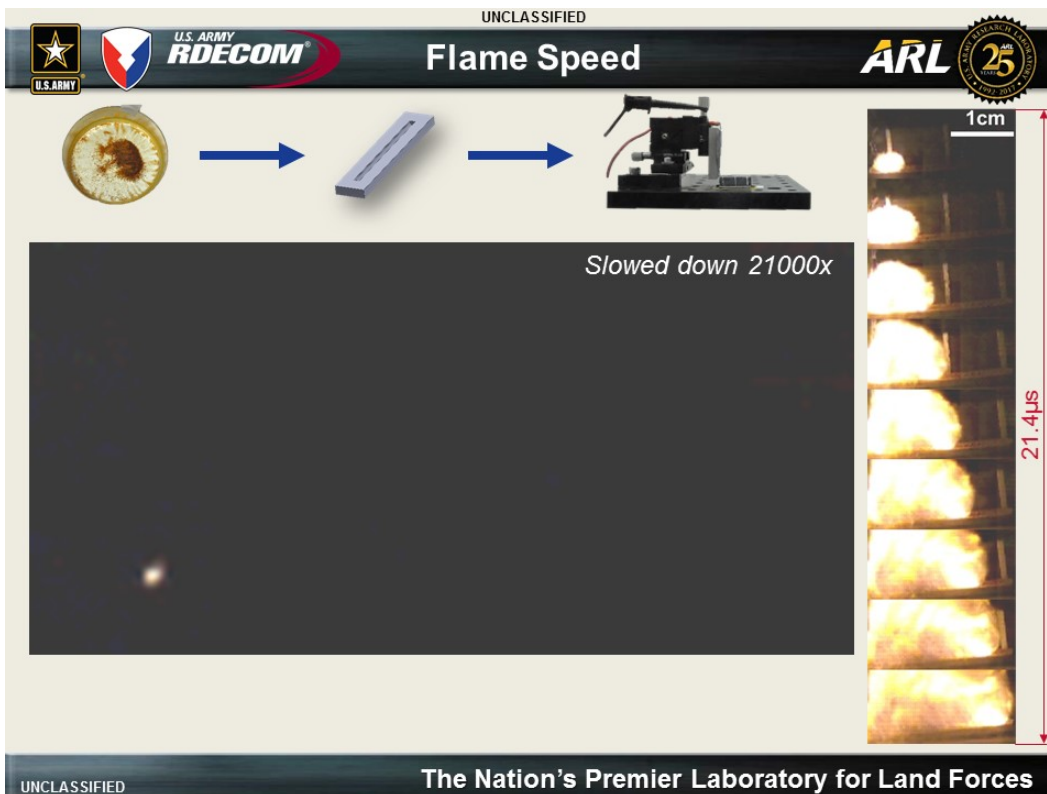
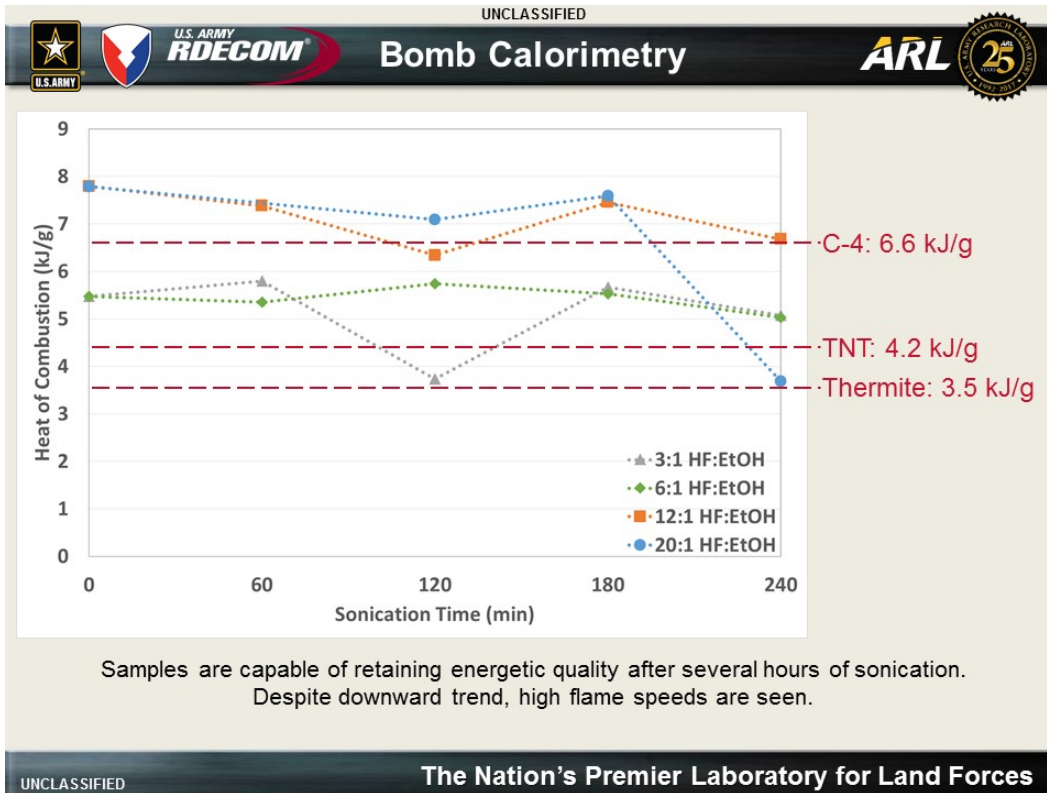
- Reduce requirements for PSi applications
- Create avenues for new applications:
  - Additive manufacturing
  - Fuel additives
  - Apply to chips without HF etch
  - Applicable to any substrate

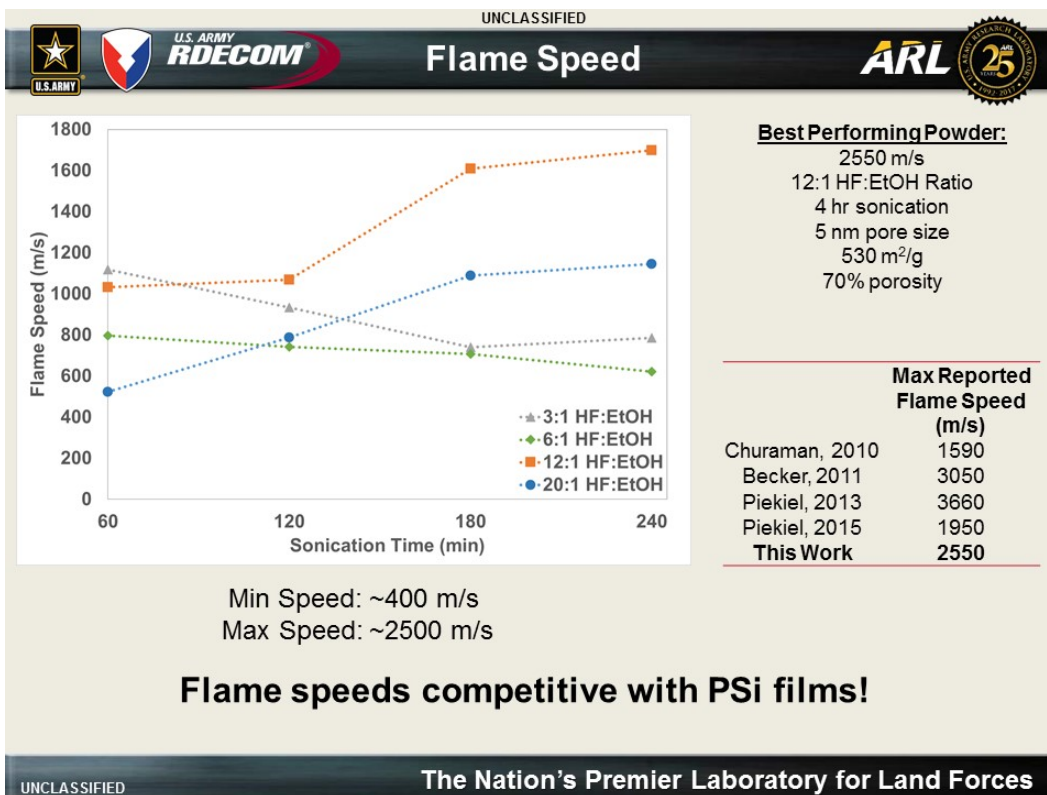
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## Future Work

**Explore sonication parameters**

- Will higher amplitude or longer time create more consistent particle sizes?

**Quantify polydispersity**

- How does the distribution of particle sizes change with sonication time?
- How does distribution of particle sizes affect flame speeds?



**Explore new methods for PSi application:**

- Inkjet printing/additive manufacturing
- Evaporation-driven assembly

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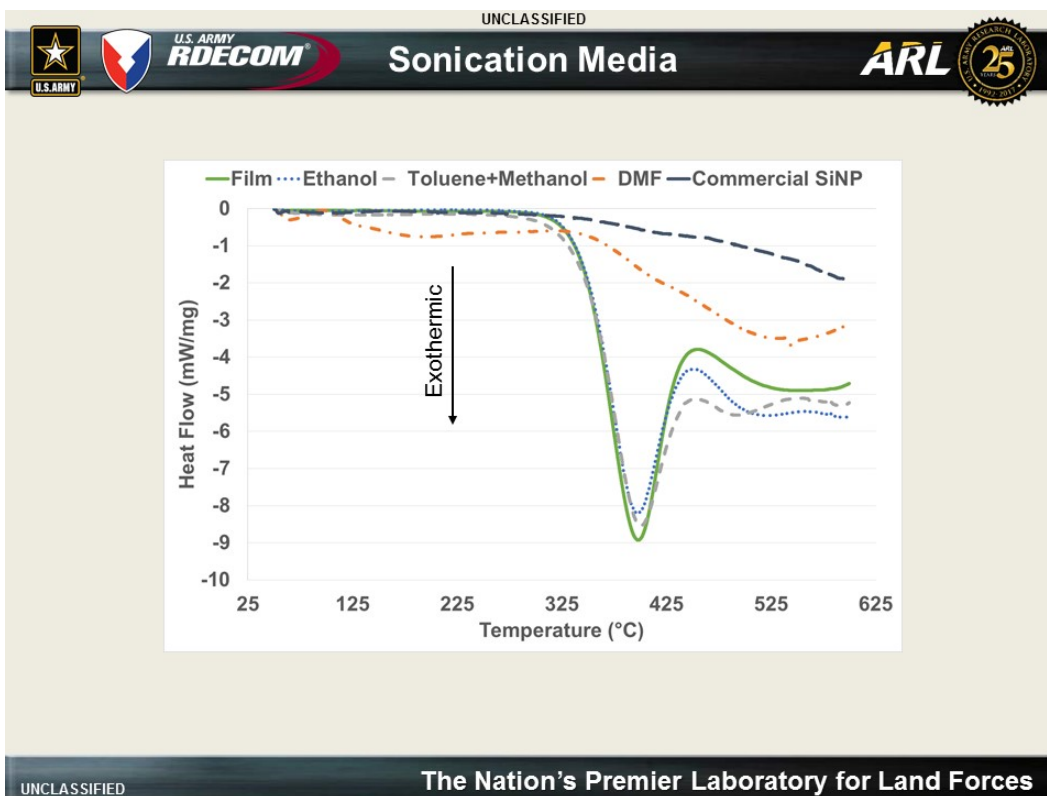
## Summary

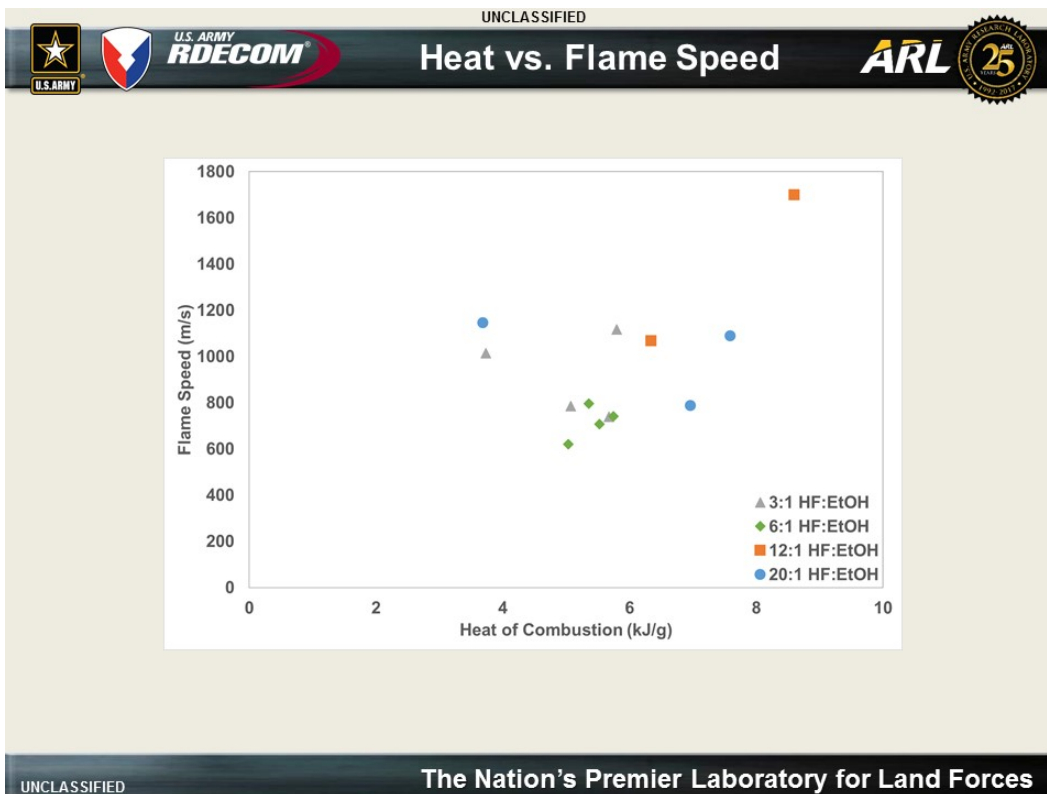
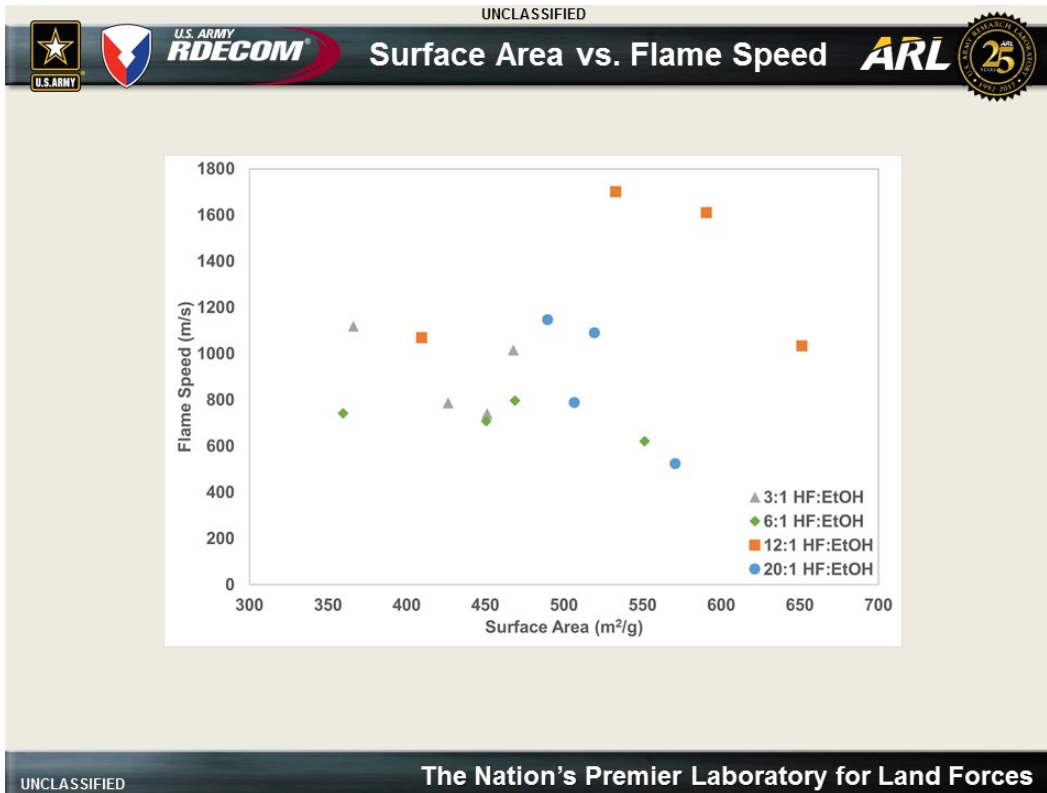



1. Particles retain **hydrogen-terminated surface** after sonication in liquid medium – important for inkjet printing applications
2. Synthesis method produces **particles <5 nm in diameter**
3. Particles retain similar **surface area & combustion properties** to original film
4. Particle **flame speeds competitive** with fastest reported for film

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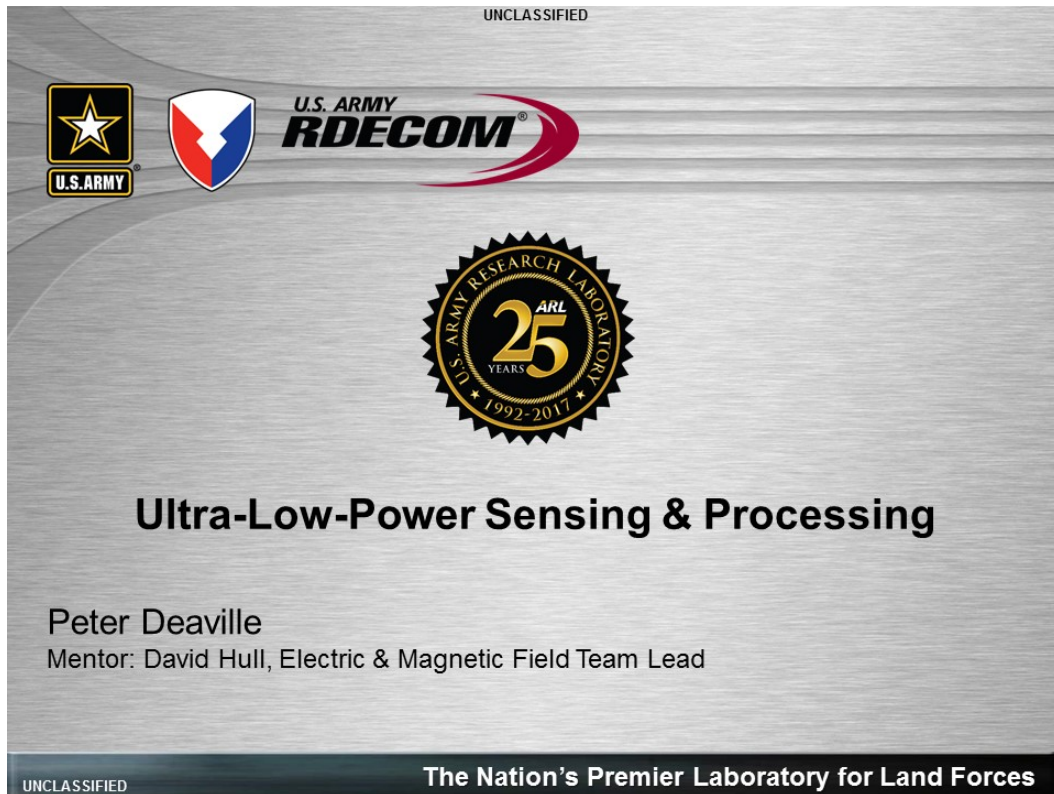




## Peter Deaville

I am a rising senior electrical engineering student at the University of Maryland, College Park. This is my first research experience and my first internship at the US Army Research Laboratory (ARL). Previously I completed a co-op in avionics integration at Bell Helicopter. My interests are in microelectronics (particularly low-power, embedded systems) and in signal processing. In the future, I hope to attend graduate school with the goal of working in research in either the public or private sector.

I would like to acknowledge the mentorship of David Hull, and the assistance of Sean Heintzelman. I had a very positive experience at ARL, and gained an invaluable amount of experience this summer.



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## Importance of Power

# ARTEMIS-Mobile Power Consumption: ~2 W

**Regular operation:**  
3 BB-2590 batteries would last  
2 weeks

**Using a 2-mW wake-up system to detect events:**

A small solar panel could power the system continuously  
(or a single BB-2590 for a year)

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## Project Overview and Methods

- Goal: compare sensing and processing methods for low-power phasor extraction**
  - Explore low-power E/H sensor options
  - Compare analog signal processing with low-power digital microcontrollers (MCUs)
  - Target <1 mW continuous operation

Aspinity RAMP Analog/Mixed Signal Processor

20 uW\*

TI MSP430 digital microcontroller

200 uW/MHz\*\*

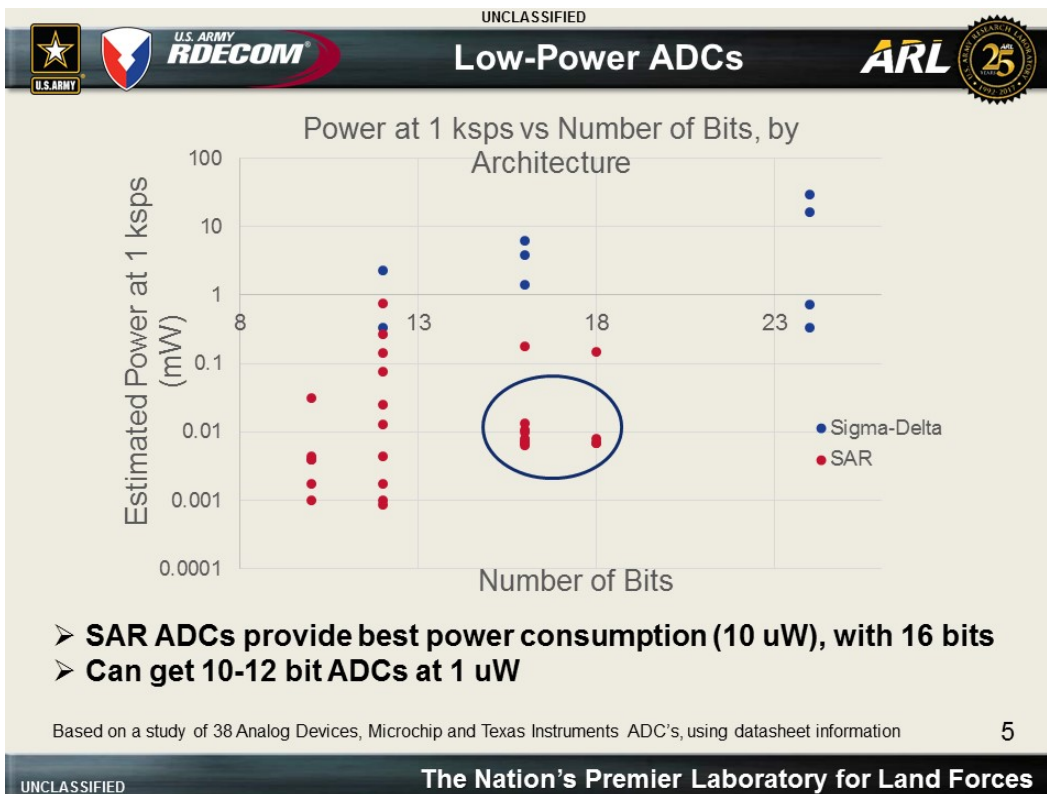
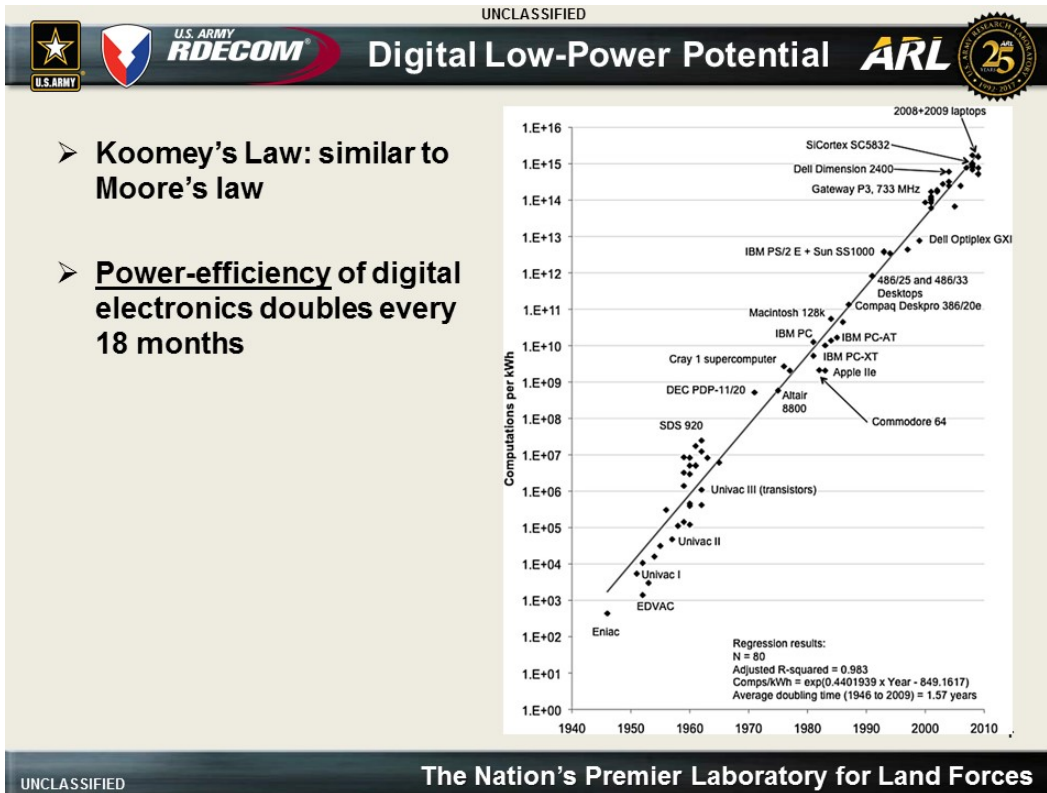
Microchip PIC digital Microcontroller

900 uW/MHz

3

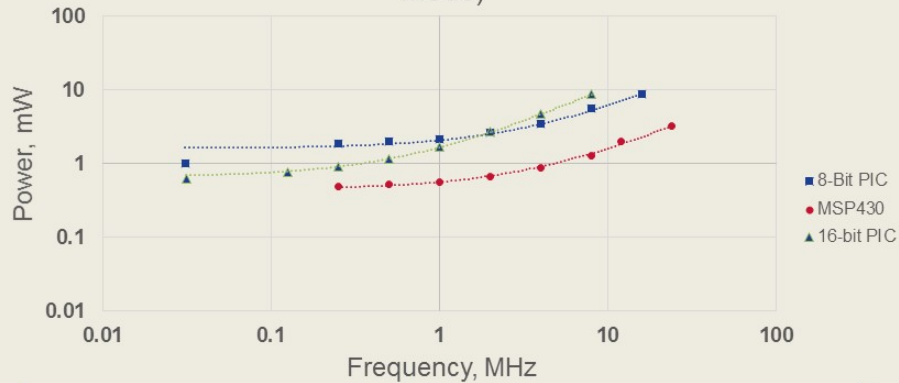
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## MSP430 vs PIC Active Mode Baseline Power Consumption

8/16-Bit PIC vs MPS430 Power vs Frequency (Active Mode)



**Only the MSP430 achieves sub-mW performance at 1 MHz**

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	TI MSP430	Microchip PIC
Active Mode Power (Baseline, 1 MHz)	570 uW	2200 uW
Idle Power	121 uW	5 – 50 uW

**The Microchip PIC series will have lower power only for applications with duty cycle < 4%**


**Therefore PIC is less useful for an always-on low-power sensor**

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## Digital Prototype: Components



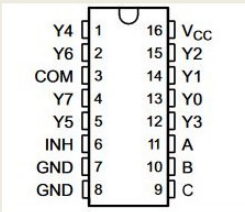
### TI ADS8866 ADC

- 16-bit SAR architecture
- Typically adds about 10 uW




### TI SN74LV4051 8-Channel Multiplexer

- 60 microwatts or less power consumption



### TI DRV5053 Hall-Effect Magnetic Sensor


- 0.288 mW with 4.3% duty cycle




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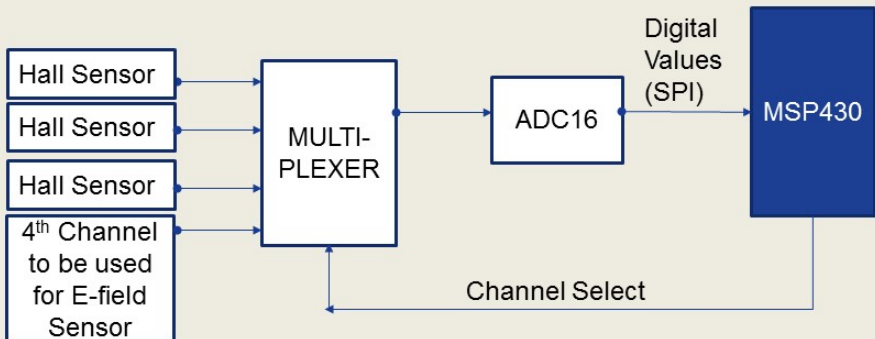
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## 16-Bit Digital Prototype





```

graph LR
    HS1[Hall Sensor] --> MUX[MULTI-PLEXER]
    HS2[Hall Sensor] --> MUX
    HS3[Hall Sensor] --> MUX
    HS4[4th Channel to be used for E-field Sensor] --> MUX
    MUX --> ADC16[ADC16]
    ADC16 -- "Digital Values (SPI)" --> MSP430[MSP430]
    MSP430 -- "Channel Select" --> MUX
    
```

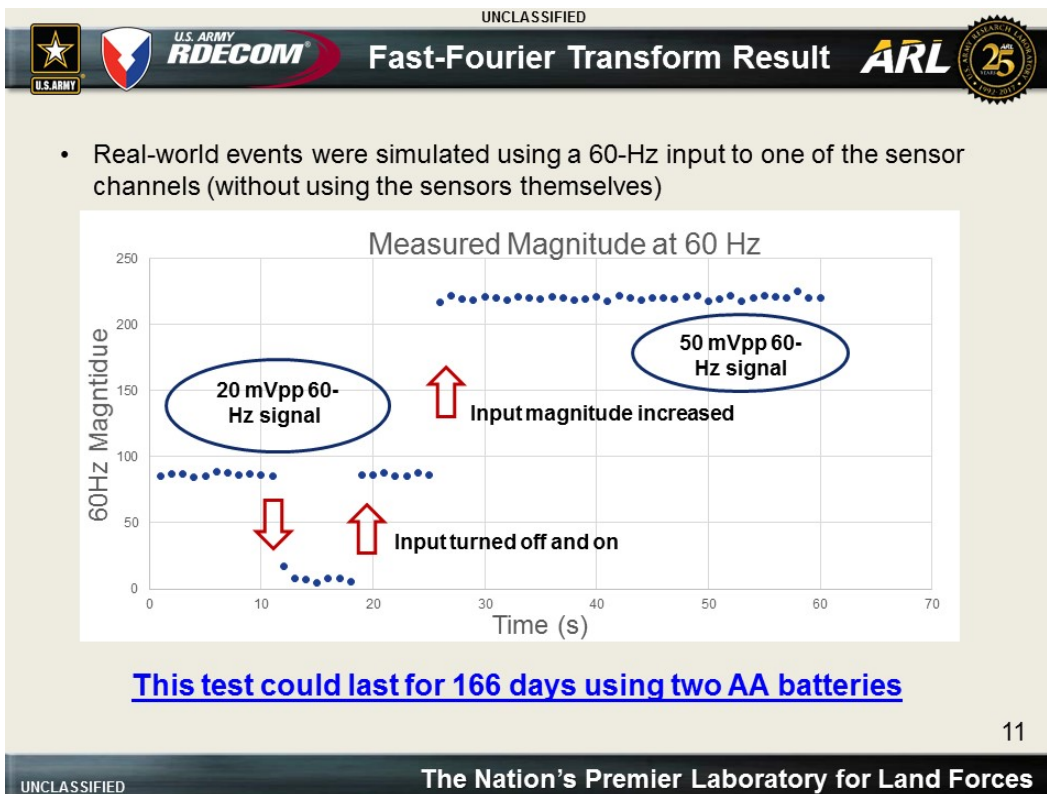
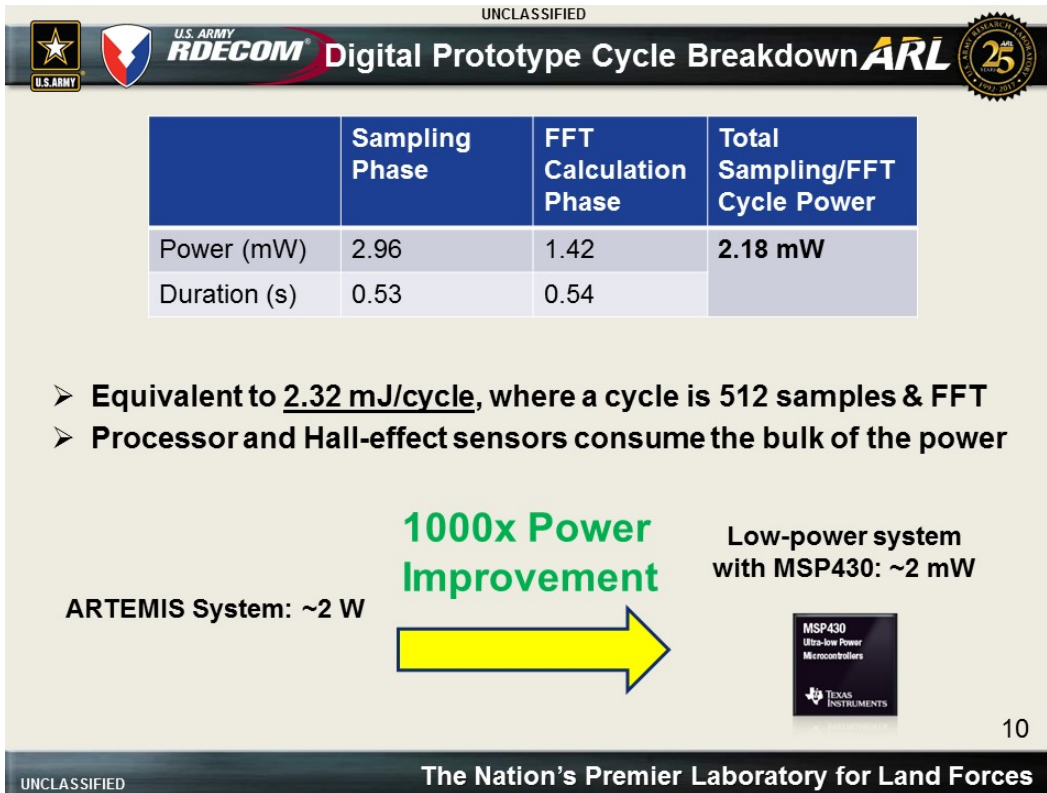
**900 uW    +    60 uW    +    10 uW    +    1100 uW\* = 2.1 mW**

**Options to reduce power:**

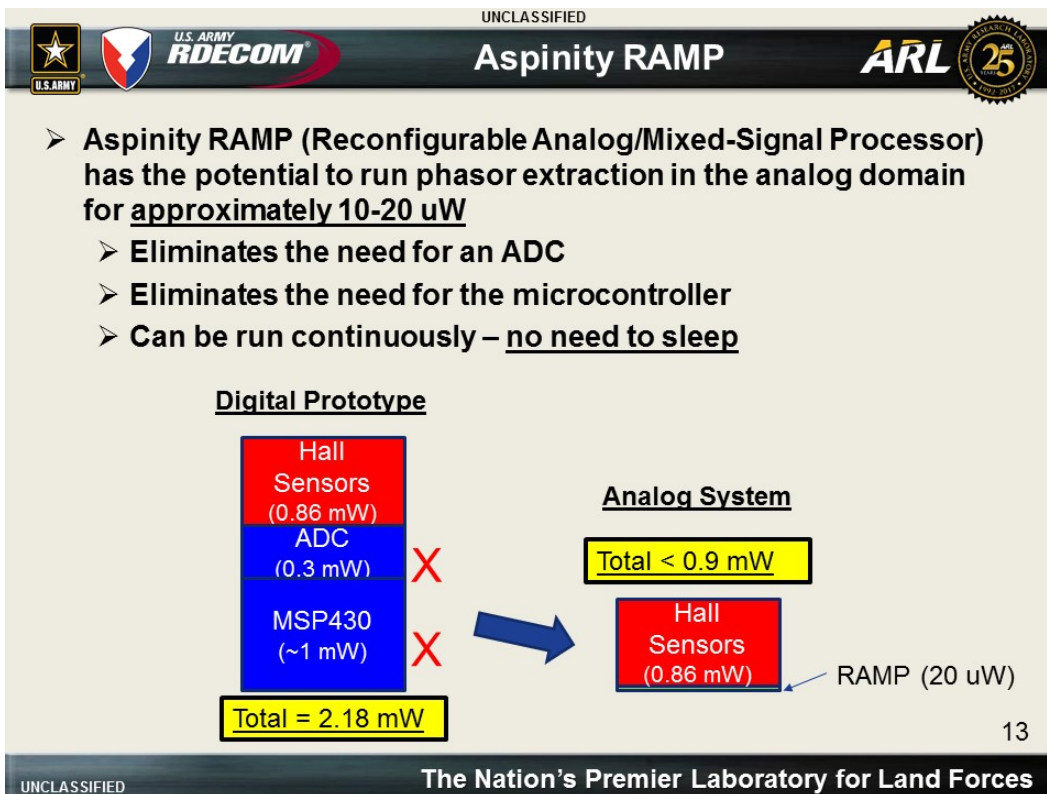
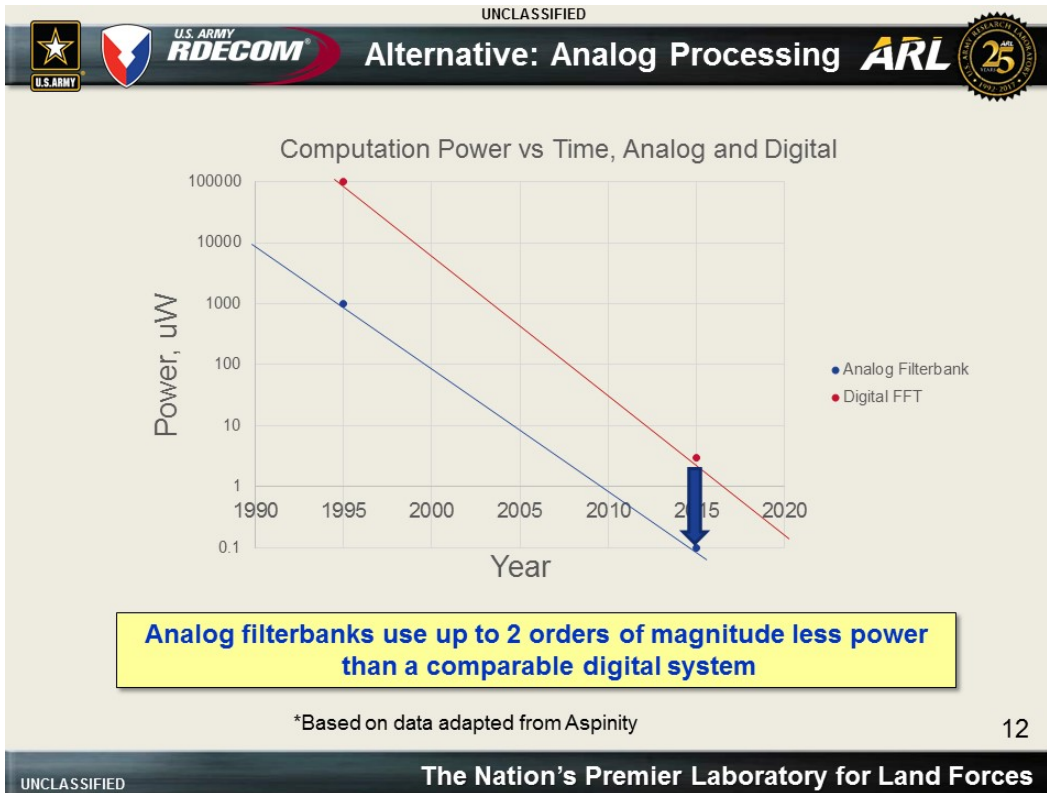
- Use 1 or 2 Hall-effect sensors (but can't do phasor calibration)
- Use new TMR magnetic sensor (100 uW/channel, but unproven/expensive)
- Use multiple MCUs (at lower clock rates) and/or co-processor

9

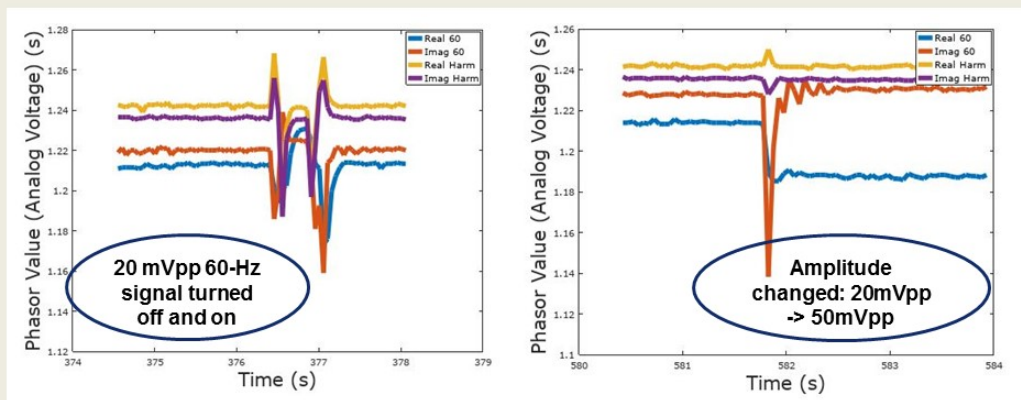
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- Similar to the digital system test, a waveform generator simulated events on the sensor input channel



This test could last for >10 years on the capacity of two AA batteries

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### Challenges

### Advantages

Does not eliminate the high power consumption of the Hall Sensors

Operates continuously for tens of microwatts

Not as easy to store and recall detailed data from before the detected event

Potential for adding sensors directly on-chip


Limited to approximately 60 dB of dynamic range (range of detectable amplitudes). With digital system, can achieve 80-100 dB.

Fewer components involved – can be used as an analog front-end as well


Unproven for use as a calibrated measurement in a standalone system

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Summary



**Digital Processing:**

- [1000x Power Improvement](#) over ARL Mobile Power Meter

**Analog Processing:**

- [2000x Power Improvement](#) over ARL Mobile Power Meter

**Both:**

- Demonstrated event detection
- Battery life improvement [from weeks to years](#)
- Potential for future power efficiency increases


*I would like to acknowledge the mentorship of David Hull, as well as the valuable assistance provided by Sean Heintzelman and Brandon Parks on the E/H Field Sensing Team.*

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Future Work



- Replace FFTs with custom phasor processing (may have similar power)
- Use multiple MCU's to split up tasks (i.e., one for sampling, one for processing)
- Add event classification to the low-power MCU, leveraging machine learning techniques
- Explore options to reach next milestone: *1 microwatt*
  - On the order of the leakage current of a small battery



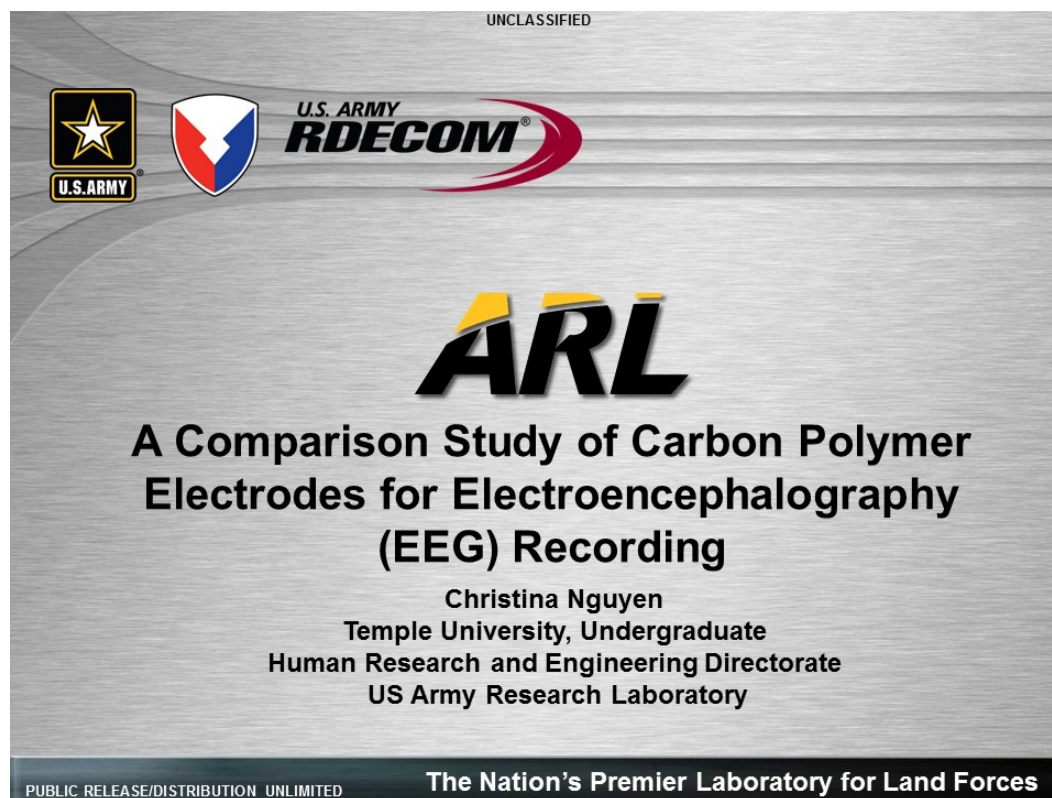
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## Christina Nguyen

Christina Nguyen is entering her senior year as an undergraduate student at Temple University, majoring in Neuroscience. She has previous research experience in the lab of Gregory Smutzer at Temple University determining thresholds for tasting different fatty acids. She also has previous experience in the lab of Chantelle Hart at the Center for Obesity Research and Education studying how adolescent sleep habits affect eating habits and weight. This summer she worked in the Mission Impact through Neurotechnology Design (MIND) lab within the Human Research and Engineering directorate under the direction of J Cortney Bradford and W David Hairston. Her work this summer focused on determining the efficacy of US Army Research Laboratory-developed carbon polymer electroencephalography (EEG) electrodes for measuring human brain signals. After graduation, she plans to attend medical school and pursue a career in both clinical work and research.






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## Summer Goals






- My background:
  - Neuroscience major
  - Psychology and biology lab experience
- Hope to contribute:
  - Use neuroscience background
  - My experience with testing subjects and developing testing protocols
  - Results that lead to further research
- Hope to learn:
  - MATLAB skills
  - Details of a career in research

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## Background: EEG



- Electroencephalography (*Vrocher et al. 2016*)
  - Measures microvolt-level electrical activity from underlying brain activity
  - Picked up by multiple electrodes on scalp
  - Recording can be visualized as a trace
- Army Usage
  - Monitor Soldier state, which can indicate Soldier performance

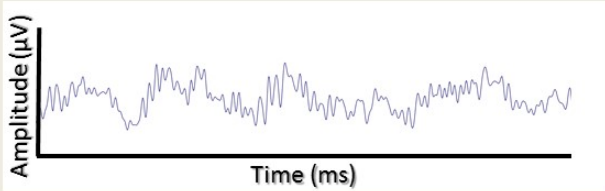




Figure 1. Example of a single raw EEG trace

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**Background: Electrodes**



- Army applications
  - Safe and comfortable field electrode
  - Reliable data collection
- Wet vs Dry (*Mathewson et al. 2017*)

Wet	Dry
Preferred clinical method	Relatively new
Better data quality	Poorer data quality
Limited usage time	Limited usage time
Difficult application/removal	Easy application/removal




Figure 2. Example of a wet EEG system

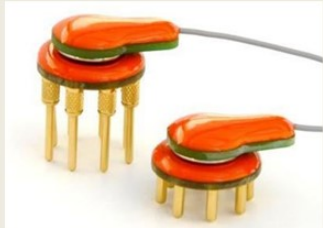




Figure 3. Example of a dry EEG system


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**Background: Electrodes**



- Solution: Polymer electrode
  - Conductive carbon nanofiber-filled polydimethylsiloxane (*Slipher et al. 2016*) → ARL collaboration
- Functions as a dry electrode without the problems associated with wet and dry
- Viable option shown through bench testing before my internship
- Never been tested on human subjects
  - My role this summer from May 2017 to August 2017 (10 weeks)




Figure 4. Top view of polymer electrode






Figure 5. Side view of polymer electrode


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## Electrode Types



- Three electrodes used:
  - g.SAHARA (dry)
  - Carbon polymer with silver epoxy coating
  - Hydrodot (wet)



*Figure 6. Side view of electrodes.*  
From left to right: hydrodot, polymer, g.SAHARA





*Figure 7. Top view of electrodes.*  
From left to right: hydrodot, polymer, g.SAHARA

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## Electrode Types



- Three electrodes used:
  - **g.SAHARA (dry)**
  - Carbon polymer with silver epoxy coating
  - Hydrodot (wet)

*Figure 6. Side view of electrodes.*  
From left to right: hydrodot, polymer, g.SAHARA

*Figure 7. Top view of electrodes.*  
From left to right: hydrodot, polymer, g.SAHARA



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Electrode Types



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From left to right: hydrodot, polymer,  
g.SAHARA



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*Figure 6. Side view of electrodes.*  
From left to right: hydrodot, polymer,  
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From left to right: hydrodot, polymer,  
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## Objective



- **Objective:** Determine the efficacy of the polymer electrodes for human EEG in recording known brain responses during decision making tasks.





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## Experimental Tasks



- Four tasks given to test electrodes' ability to record known brain responses and its susceptibility to noise
- Focus was using a rapid serial visual presentation (RSVP) task (*Ries et al. 2013*)
  - Images flashed every 500 ms (target, distractor, background)
  - Button press in response to only target stimuli




Figure 8. Target –  
Button press




Figure 9. Distractors – No  
button press




Figure 10. Background –  
No button press

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Figure 9. Distractors – No  
button press




Figure 10. Background –  
No button press

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## Event Related Potential (ERP)

- ERP: Measured brain response that is linked to a specific event
- What is P300?
  - Component of ERP
  - Decision making tasks provoke P300 response
- Why P300?
  - Well documented → High reproducibility
  - Differing amplitudes depending on stimuli (*Ries et al. 2013*)

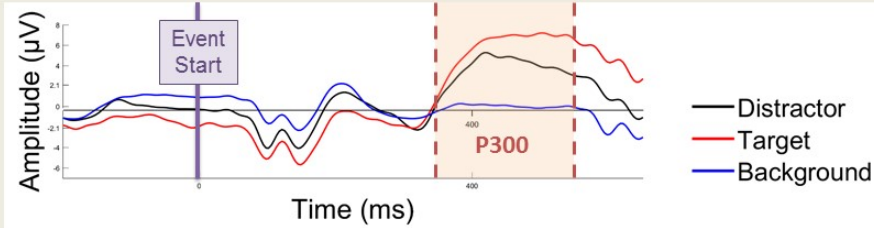


Figure 11. Example of an expected P300 response

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- Three different curves
  - Target: Largest amplitude
  - Distractor: Second largest amplitude
  - Background: Same amplitude as baseline

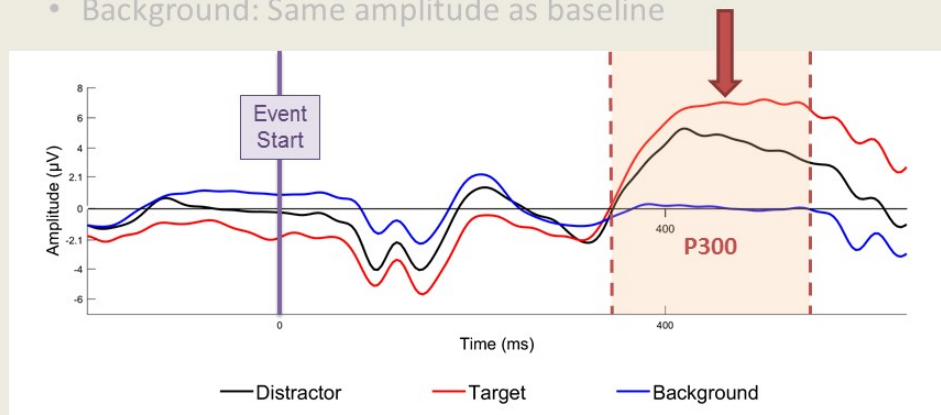


Figure 12. Example of expected curves for different stimuli

9

- Three different curves
  - Target: Largest amplitude
  - Distractor: Second largest amplitude
  - Background: Same amplitude as baseline

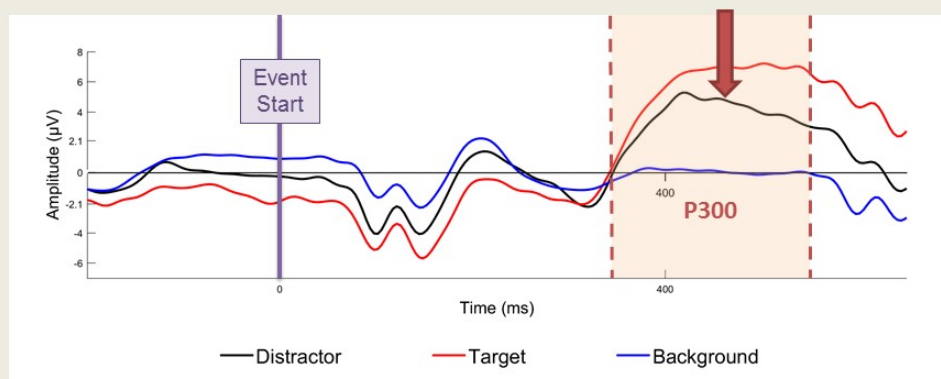


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9



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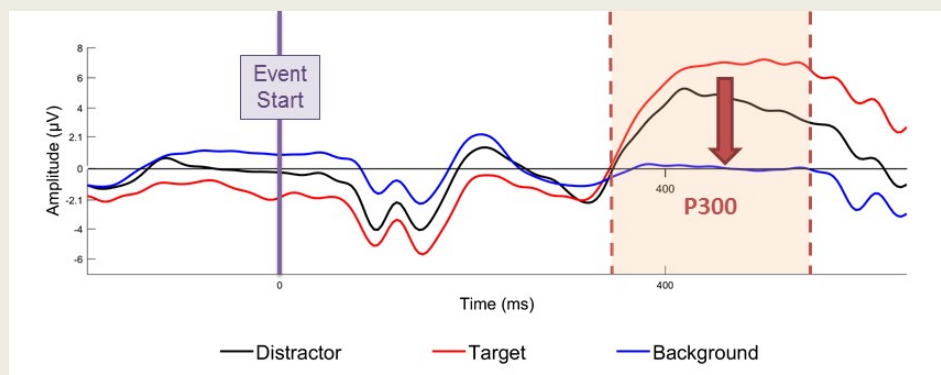


Figure 12. Example of expected curves for different stimuli

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- **Hypothesis:** Our polymer electrodes will record a P300 response with the target having the highest amplitude, followed by the distractor and background.

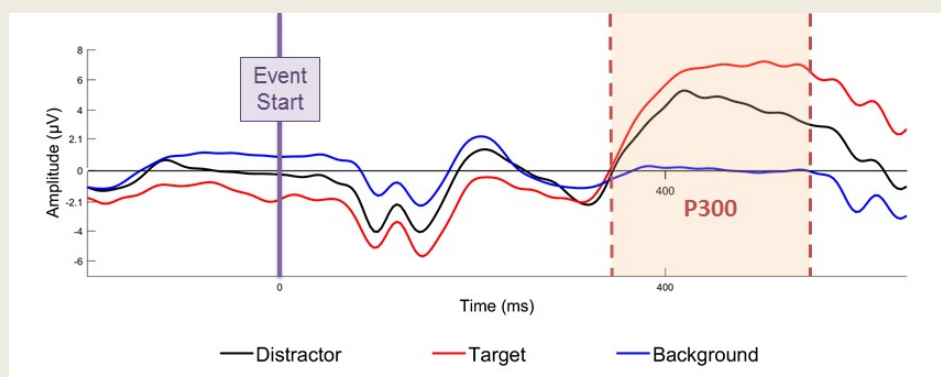


Figure 12. Example of expected curves for different stimuli

10

- Custom headset design with designated 10 – 20 locations
  - Fpz, Cz, Pz, Oz (three electrodes per region)
  - Three electrooculogram (EOG) sites
  - Sixteen-channel g.SAHARA EEG system; 15 channels used

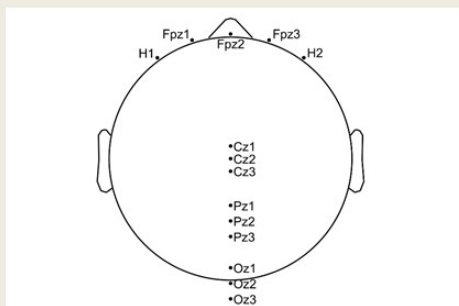


Figure 13. Channel locations based on 10-20 system



Figure 14. Top view of custom headset

11

- Custom headset design with designated 10 – 20 locations
  - Fpz, Cz, Pz, Oz (three electrodes per region)
  - Three electrooculogram (EOG) sites
  - Sixteen-channel g.SAHARA EEG system; 15 channels used



Figure 15. Posterior view of custom headset with electrodes snapped in



Figure 16. Side view of custom headset with electrodes snapped in

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- Sixteen subjects; only used 9 subjects
  - Each subject needed all 3 electrode types with sufficient data quality or else rejected
- Dry electrodes often were the issue
  - g.SAHARA and polymer electrodes were equally the cause of subject rejection

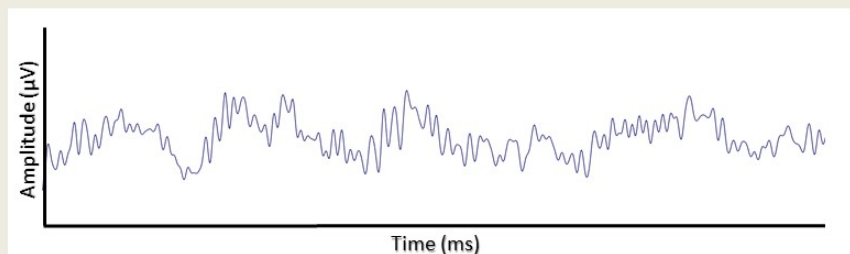
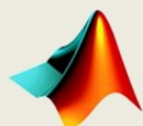


Figure 17. Example of a single EEG trace

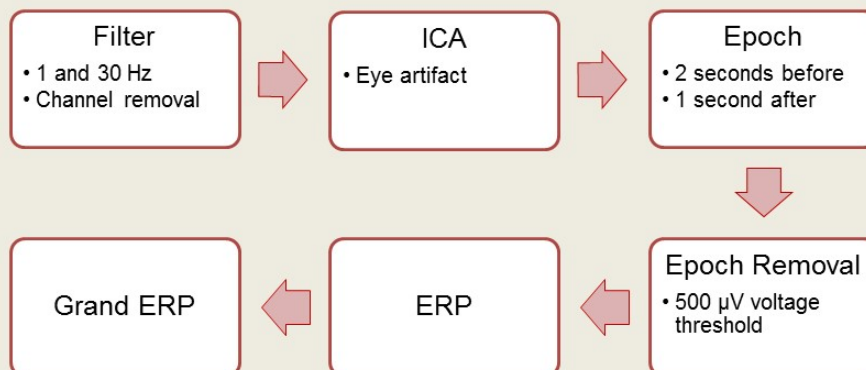
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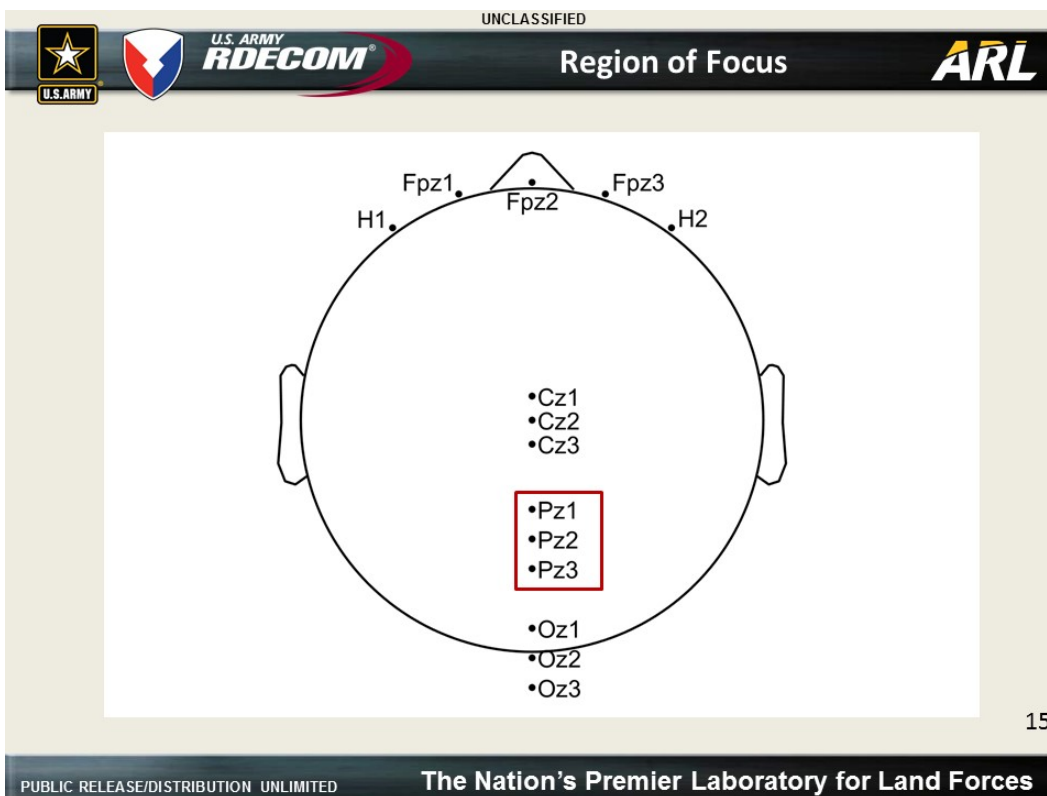
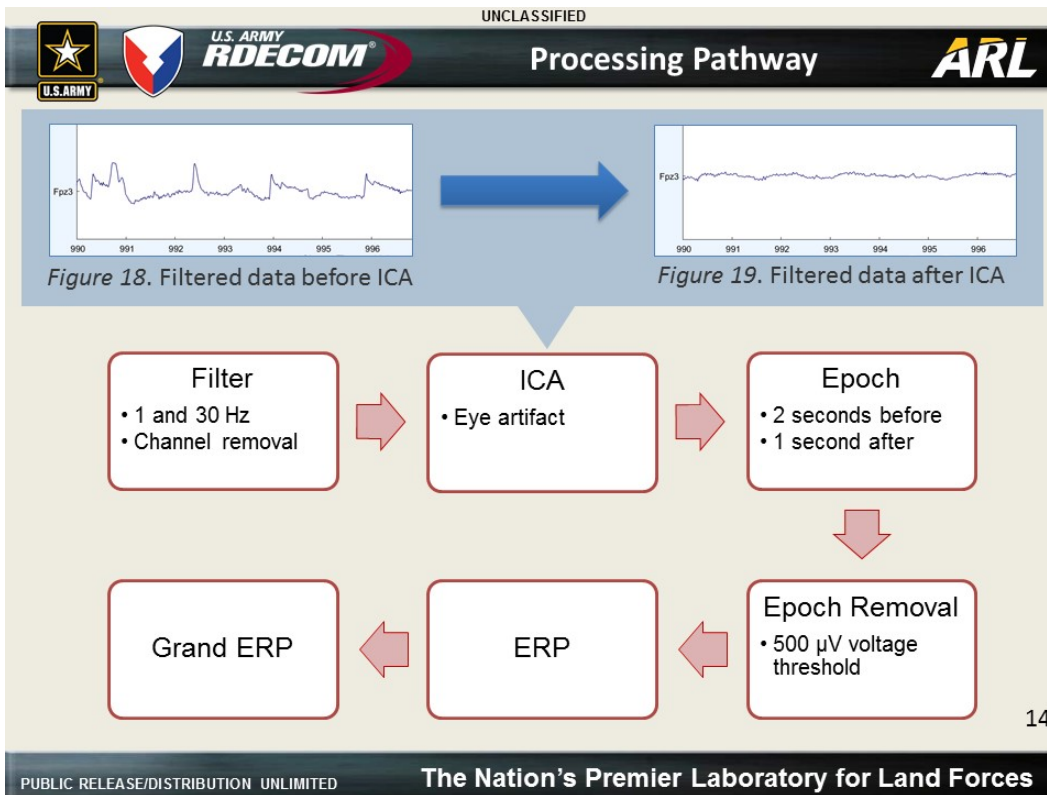
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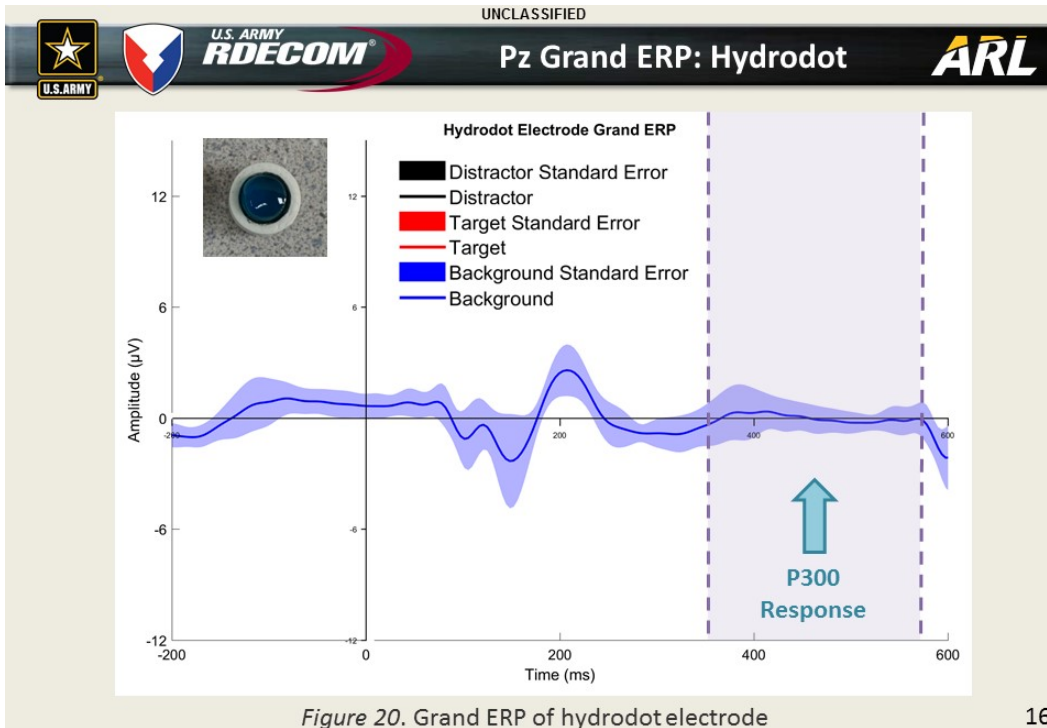
EEGLAB



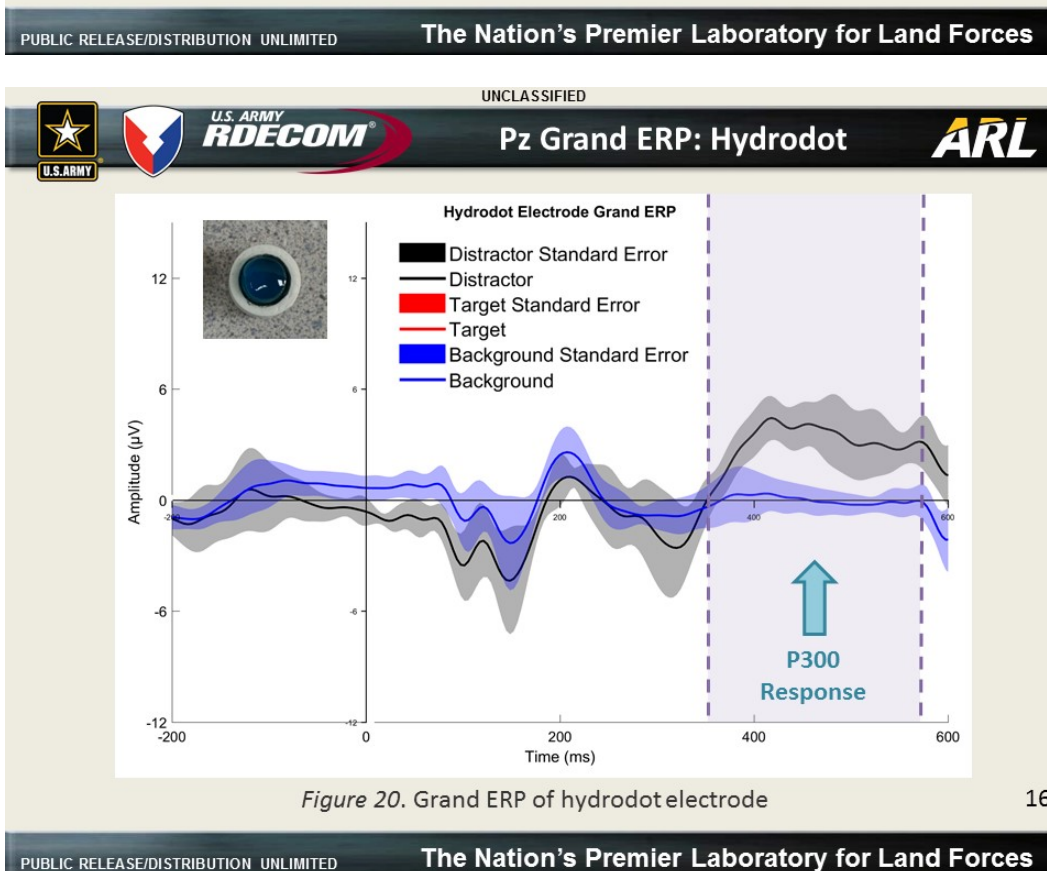
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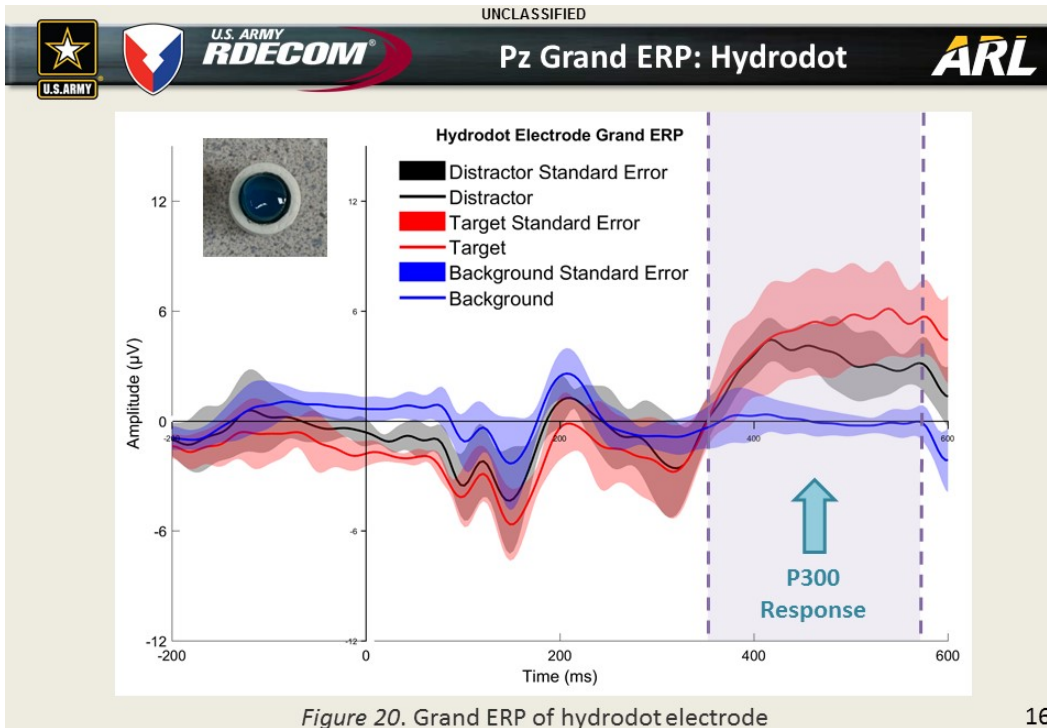




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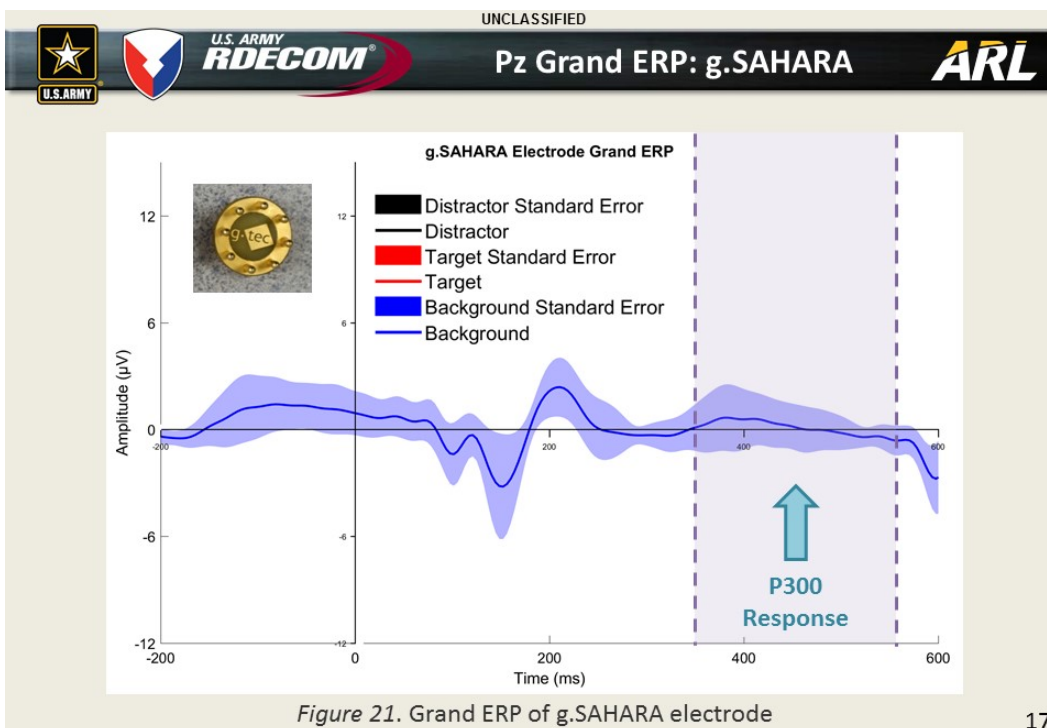


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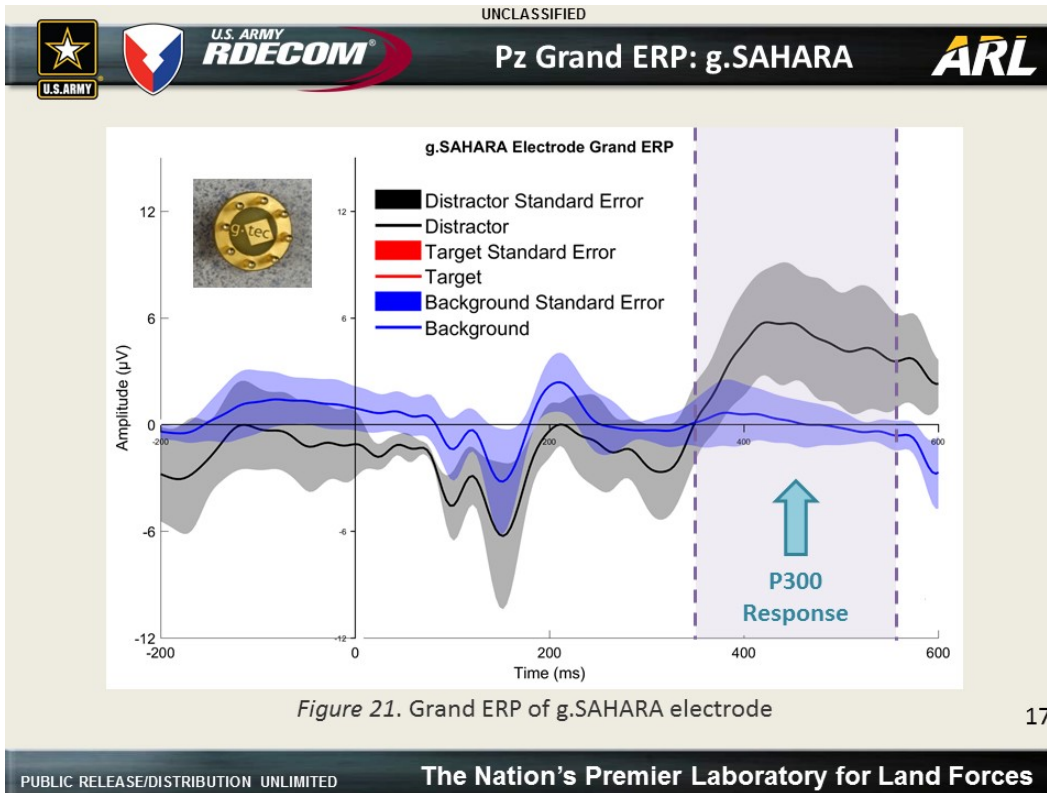
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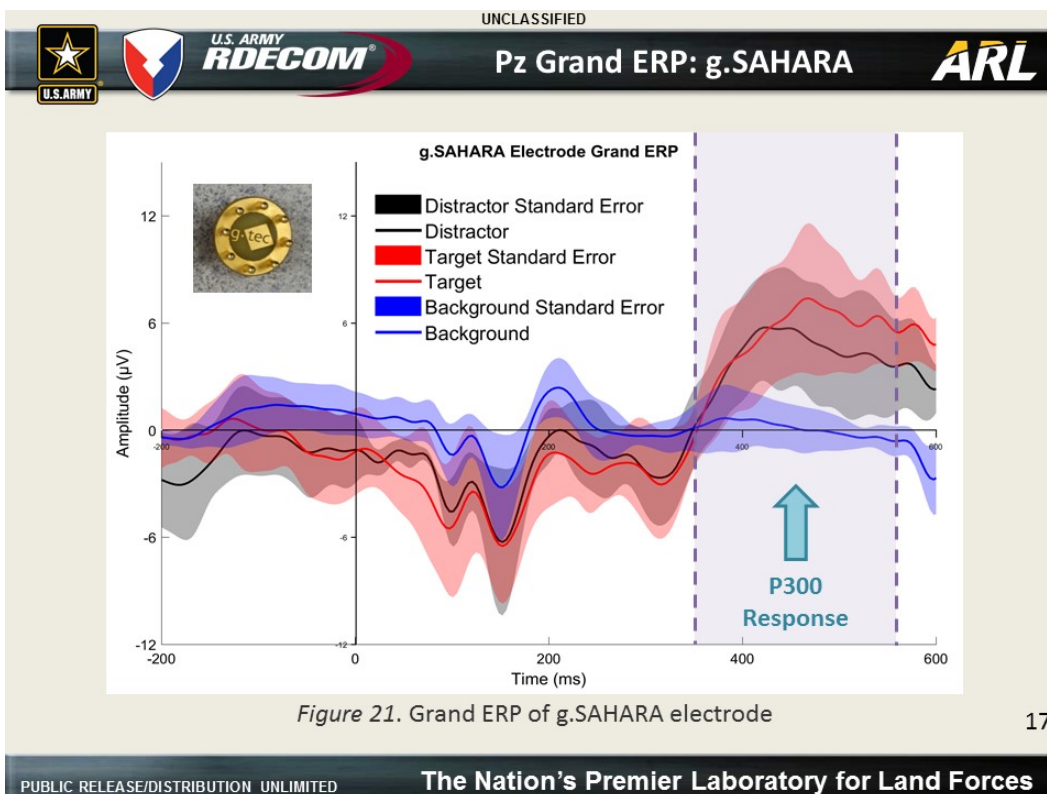


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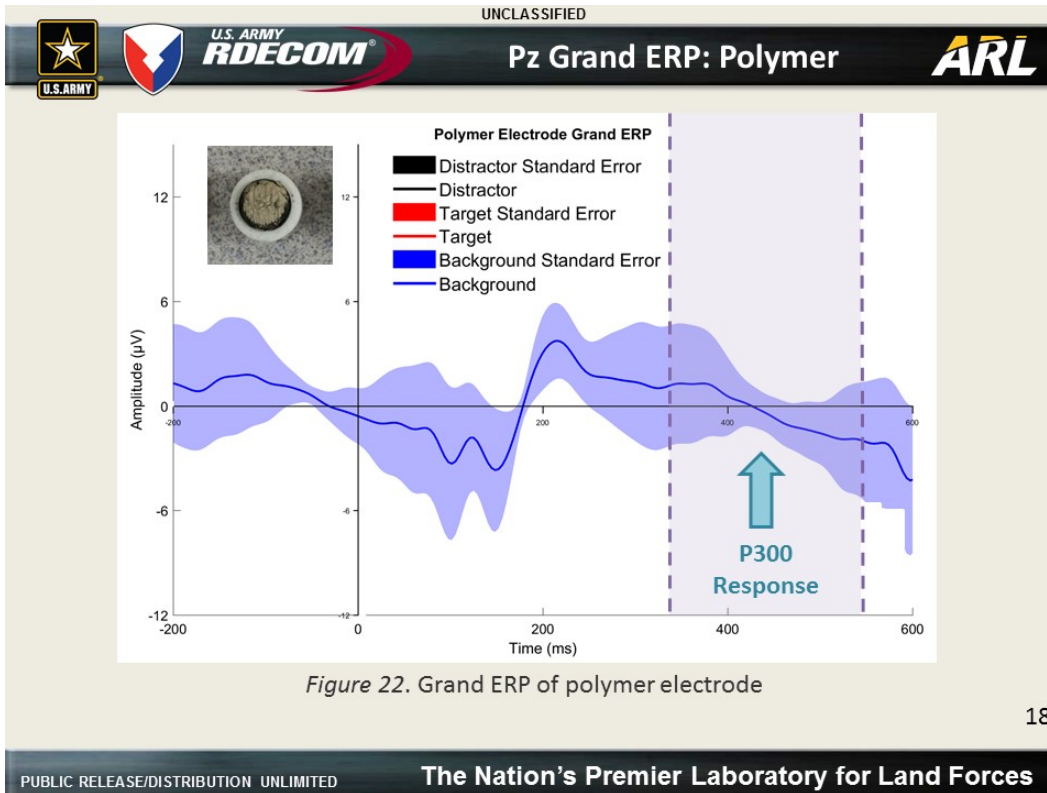


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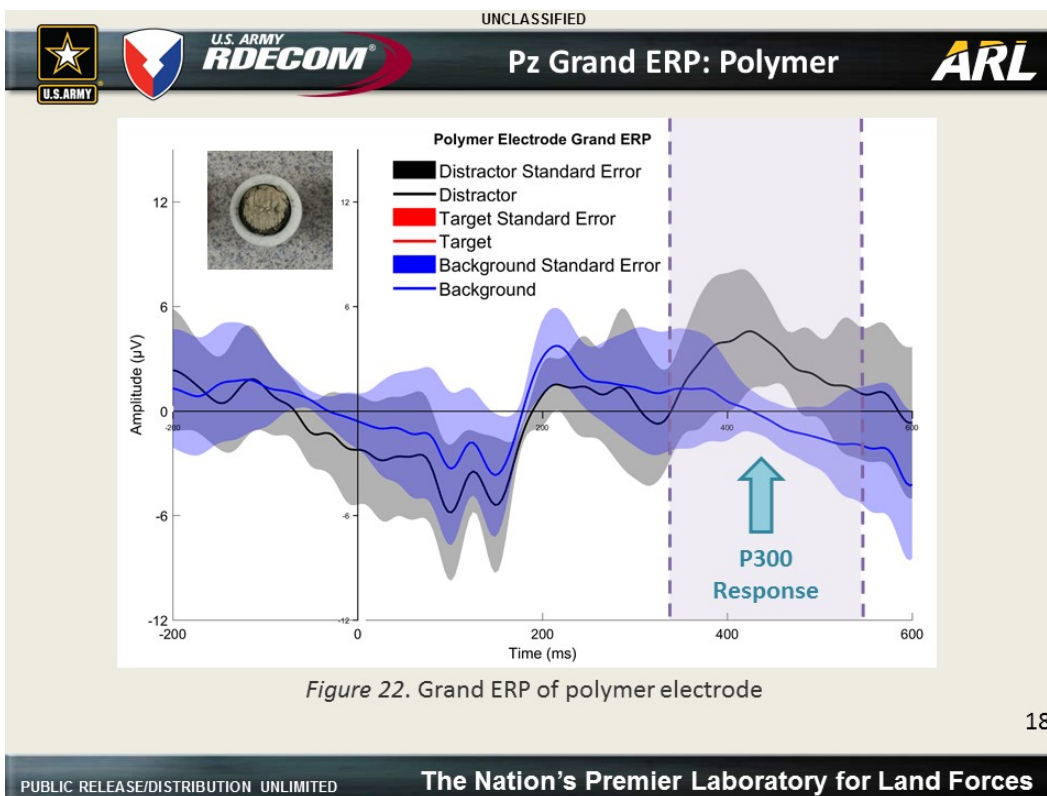


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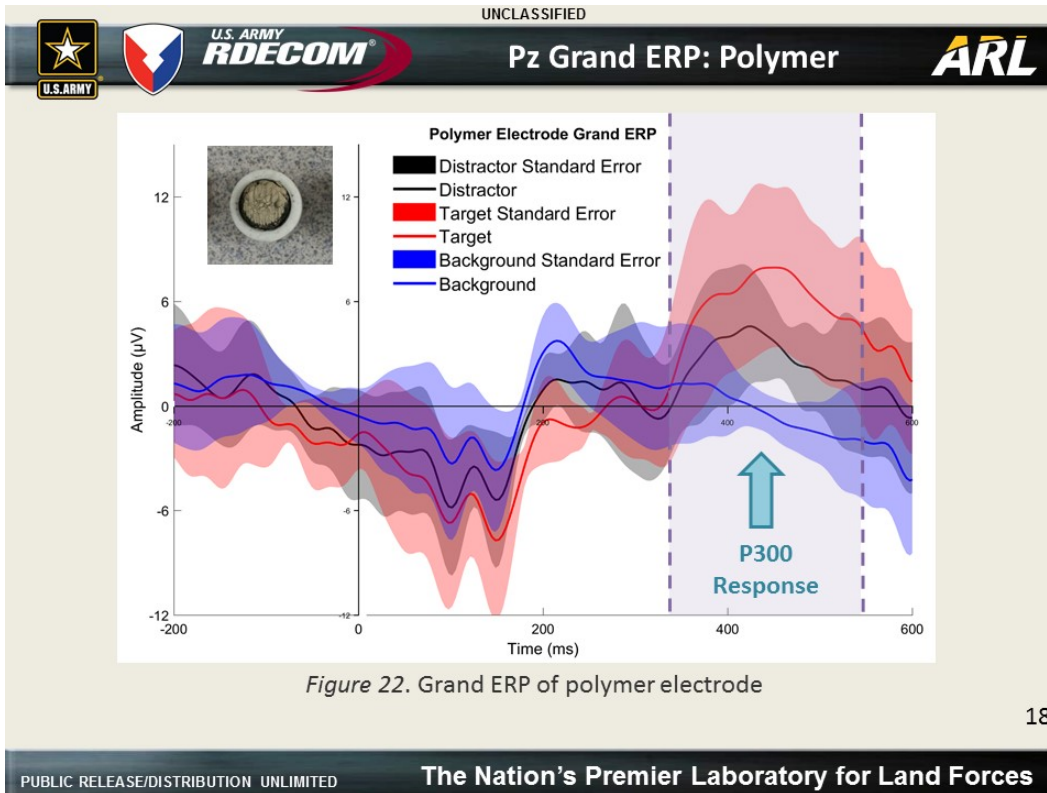




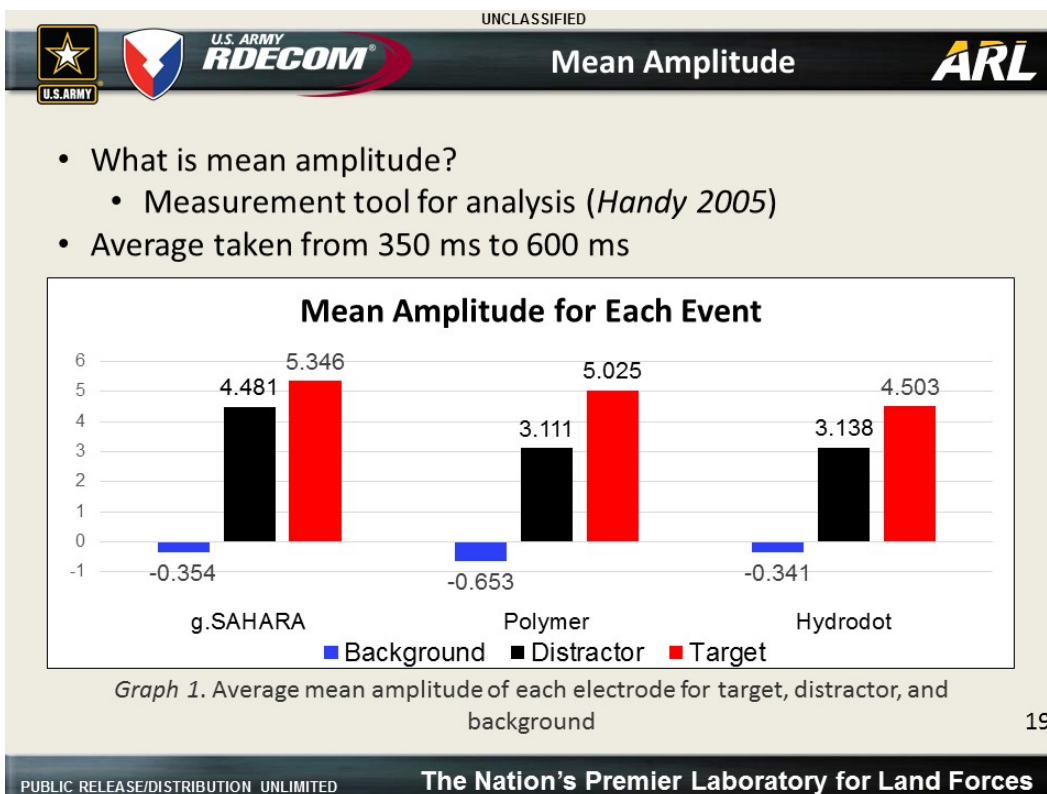
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**Mean Amplitude Paired t-Test**

- Used a paired t-test with Bonferroni correction to determine whether differences between conditions were significant
- Preliminary results show significant differences for target/background and distractor/background

	<b>g.SAHARA</b>	<b>Polymer</b>	<b>Hydrodot</b>
<b>Target/Distractor</b>	p = 0.181 t = 1.466	p = 0.0532 t = 2.267	p = 0.0515 t = 2.287
<b>Target/Background</b>	p = 0.000145 t = 6.753	p = 0.000948 t = 5.084	p = 0.0000264 t = 8.574
<b>Distractor/Background</b>	p = 0.0024 t = 4.365	p = 0.000670 t = 5.369	p = 0.0000860 t = 7.274

*Table 1.* Achieved p-values when comparing differing conditions across the three electrode types. Green is significant and red is not significant.  
Used  $\alpha = 0.017$ . Degrees of freedom = 2.

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**Discussion**



- All 3 electrodes were able to measure an ERP with the characteristic P300 signal and amplitude pattern.
- All electrodes could detect a significant difference between distractor/background and target/background.
- None of the electrodes could detect a significant difference between target/distractor.
- Power analysis suggests a sample size of  $n = 10$ .
  - Data collection is ongoing




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Conclusion

- Objective reached, hypothesis supported
  - Polymer electrode was able to record the expected P300 response for the target, distractor, and background.
- Promising alternative for safe, comfortable electrodes for Army usage in the field
- Issues with current electrode geometry
  - Hard to get through hair with polymer electrode
- Analyze data from artifact-inducing tasks in experiment
  - We only looked at recording known brain responses.

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Summer Take Away

- Contributions:
  - Designed a novel headset for electrodes
  - Collected data on human subjects
  - Developed my own processing pipeline for EEG analysis
- Knowledge gained:
  - Hands-on experience with EEG
  - MATLAB skills
  - Experience in a research-oriented career
  - The military applications of neuroscience research


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## Acknowledgements





- Lab Mentors
  - Cortney Bradford
  - Dave Hairston
- Fellow CQL intern
  - Ben Burke – Poster with additional analyses on the floor

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# Supplementary Slides

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RDECOM** **Power Analysis** 

- t-Test is affected by sample size and effect size → small sample is not reliable
- Conducted power analysis to find preferable subject number based on effect size and power of previous studies (*Mathewson and al. 2017*)
  - Two-tailed t-test
  - $\alpha = 0.017$
  - Power = 0.979
  - Effect size = 1.696
  - **10 subjects**


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**Effect Size of Mean Amplitude**



- Found effect size of statistically significant results with estimated standard error of effect size
- These differences had a large effect (desire > 0.5)

	<b>g.SAHARA</b>	<b>Polymer</b>	<b>Hydrodot</b>
<b>Distractor/ Background</b>	2.21 (S.E.: 0.59)	2.53 (S.E.: 0.62)	3.51 (S.E.: 0.73)
<b>Target/ Background</b>	2.97 (S.E.: 0.67)	2.93 (S.E.: 0.66)	3.06 (S.E.: 0.68)

Table 2. Effect size of statistically significant conditions in relation to desired effect size

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## Clarence Wong

I am from Knoxville, Tennessee, and I graduated with a BS in electrical engineering in May 2017 from the University of Tennessee. As an undergraduate, I studied under Dr Garrett Rose and researched Neuromorphic VLSI Circuit Design and Neuromorphic Computing. In the fall, I will return to the University of Tennessee to start my master's program in electrical engineering. As a master's student under Dr Rose, I will be involved with designing neuromorphic applications and platforms for testing different neuromorphic architectures. After I complete graduate school, I intend to work in industry as a project manager.



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## About Me

- From: Knoxville, Tennessee
- School: University of Tennessee
- Degree: BS in electrical engineering
- Starting Masters in electrical engineering in the Fall
- Undergraduate Research: Neuromorphic Circuit Design and Applications
- Been with ARL for 12 weeks
- cwong11@vols.utk.edu

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## Moore's Law

- The number of transistors on a chip doubles about every 2 years, thus improving computing performance.
- The computing performance associated with Moore's Law has begun to plateau due to the sizing transistors below 10 nm and quantum tunneling.
- Using Neuromorphic Computing to go overcome Moore's Law.

### 115 Years of Moore's Law



<https://www.globalsilicon.com/pressroom/2017/02/19/exploring-opportunities-in-artificial-intelligence/>

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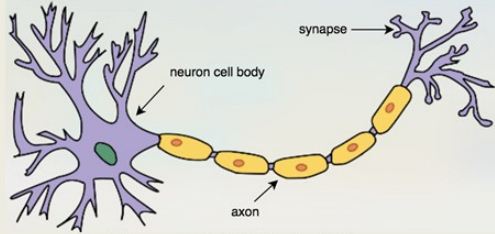
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## Neuromorphic Computing

- **Neuromorphic Computing:** mimicking biology and the brain using integrated circuits
- **Advantages:** size, weight, and power (SWP)
- **Programmable Neuromorphic Hardware** e.g. IBM TrueNorth
- **Synapses** – determine the amount of action potential (charge/weight) to send to a neuron
- **Axon** – connection between neurons and synapses
- **Neurons** – collect action potential and spikes when a threshold is met





[https://commons.wikimedia.org/wiki/File:Neuron\\_-\\_LangNeutral.svg](https://commons.wikimedia.org/wiki/File:Neuron_-_LangNeutral.svg)



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## Project Description

- The idea of merging Neuromorphic Computing and robotics. As well, merging theory and simulation with real world applications.
- Overall Goal - Design a platform for testing:
  - Different neuromorphic hardware (e.g., TrueNorth, FPGA)
  - Architectures (e.g., TrueNorth, MrDANNA, DANNA)
  - Training methods (e.g., supervised, unsupervised, online, offline)
  - Connecting hardware (e.g., sonar, camera, motor, LIDAR, phones)
- Short term goal
  - Design a Collision Avoidance Robot that drives autonomously using Neuromorphic Hardware.
- Work based off of University of California, Irvine's Jeff Krichmar and research group. Project differs by hardware, learning algorithms, and application used.

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## Collision Avoidance Robot

- **Purpose:** Autonomously avoid colliding into objects using IBM TrueNorth and Convolutional Neural Networks (CNN) to determine the output motor response.
- Three sonar sensors placed on the left, center, and right side of the car are used to detect objects.
- Four predefined motor control commands: Forward, 90 degree left turn, 90° right turn, and reverse
- Two main components to the project: Robotics/Electronics and Neuromorphic Process



<http://www.dagurrobot.com/goods.php?id=154>


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## Electronics


- Three sonar sensors – measures the amount of time the sound wave bounces back to the object and produces an analog output
- Arduino Mega – programmable microcontroller written in Arduino's version of C/C++
- Motor controller – intermediary between the Arduino and DC motors to control speed and direction of the motor
- Serial Bluetooth module
- Six DC motors – tank control method (turning controlled by stopping or reducing the speed of the left or right motor)
- IBM TrueNorth – programmable neuromorphic chip




[https://www.mikrobotix.com/Ultrasonic\\_Sensors/MB1002.htm](https://www.mikrobotix.com/Ultrasonic_Sensors/MB1002.htm)



<http://www.electrochips.com/1963/arduino-mega-2560-pinout/>



<http://www.robotshop.com/en/codewarrior-2x456-6-340v-regenerative-motor-controller.html>

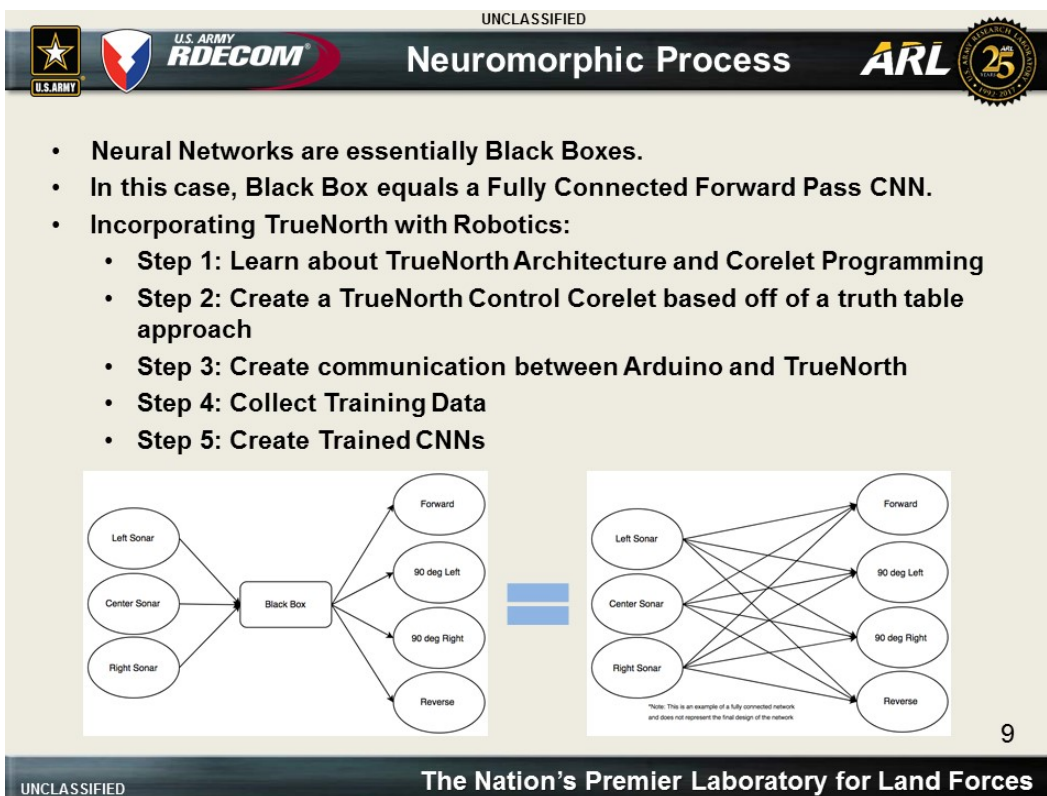
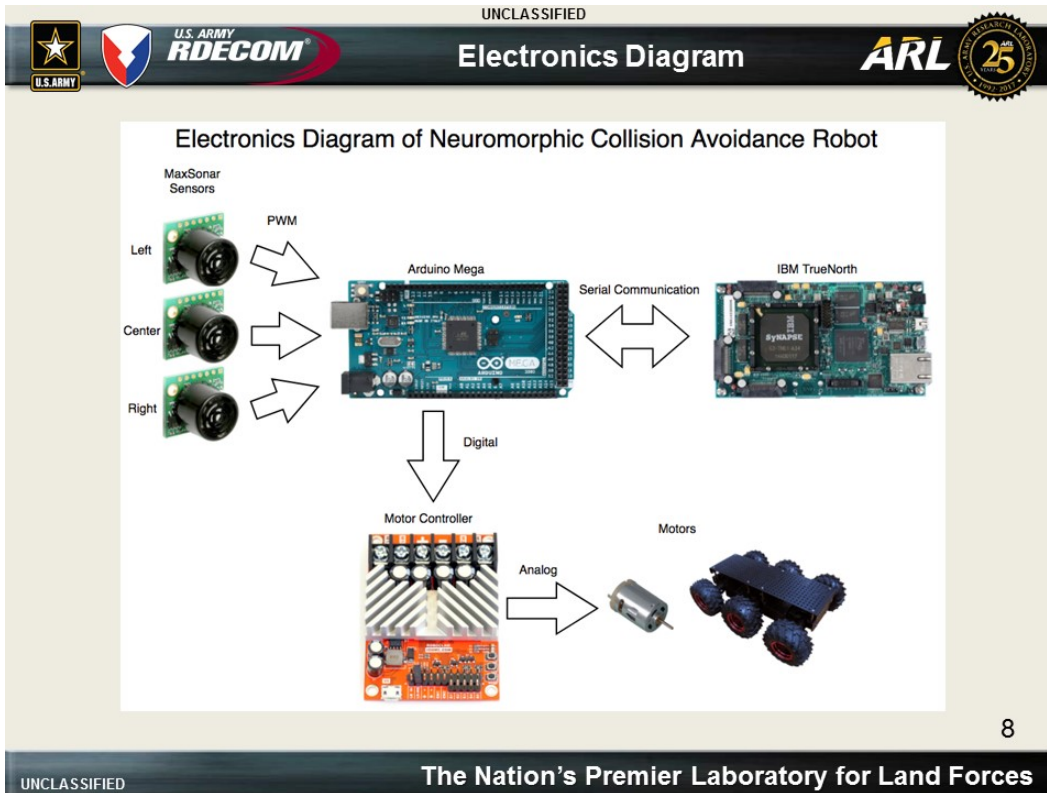




<http://blog.ibmstart.net/2015/09/10/true-north-next-generation-cognitive-computing/>

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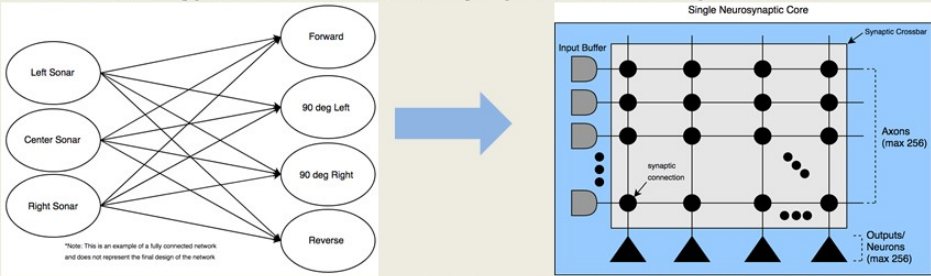



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## TrueNorth and Corelets



- IBM TrueNorth – programmable neuromorphic chip
- Corelet programing – process of converting neural networks into the TrueNorth framework (Matlab functions provided by IBM)
- Corelet Process: set up input and output pins, Neurosynaptic Cores, Synaptic Crossbar, and Neuron parameters (e.g. weight, threshold) which produces model and connection files that can be imported to TrueNorth
- TrueNorth Constraints - 4,096 Neurosynaptic Cores, maximum of 256 Neurons and Axons per core, maximum of 65,536 Synapses per core
- Four axon types – maximum of 4x256 different weights
- 256 neuron types – maximum of 256 synaptic connections per neuron



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## Control Corelet

- Translating a truth table into a fully connected Corelet
- No learning– determined the neuron parameters and framework by hand
- Focus: learn how to correctly utilize the IBM provided Matlab functions used to set up the input and output connections, crossbar, and neuron parameters
- Truth Table:
  - 1 represents the sonar value is below a user defined value/ object is close
  - 0 represents the sonar value is above a user defined value

Sonar Range (Inches)			Corresponding Motor Direction
Left	Center	Right	
41	24	22	Left
15	23	30	Right
35	78	29	Forward

1 represents when a sonar sensor receives a reading below a specified range.  
 0 represents when a sonar sensor does not receive a reading below a specified range.  
 F = Forward  
 L = Left  
 R = Right  
 Rev = Reverse  
 Order of Priority:  
 F -> L -> R


Left	Center	Right	Output
0	0	0	F
0	0	1	F/L
0	1	0	L/R
0	1	1	L
1	0	0	F/R
1	0	1	F
1	1	0	R
1	1	1	Rev

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## Communication Between Arduino and TrueNorth



- Physically connected using USB
- TrueNorth has Ubuntu on it
- Import model and connection files created by the Corelet onto TrueNorth
- Python script runs the model and connection files on TrueNorth, and reads and writes serial data between the Arduino and TrueNorth
- Python script utilizes multiprocessing by splitting up the processes of reading data, running the Corelet, and writing the data



Serial Communication



**TrueNorth Communication (Python)**


```

graph TD
    A[Read Serial Data/  
Sonar Data] --> B[Convert Input  
Data into Spikes]
    B --> C[Input of Neural Network]
    C --> D[Run Data through  
Neural Network/  
Model File]
    E[From Model and  
Connection files] --> D
    D --> F[Output Response  
In Spiking Format]
    F --> G[Translate Output Response]
    G --> H[Write Serial Data to Arduino/  
Motor Command]
        
```


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## Collecting Training Data



- Supervised Learning - mapping 3 sonar values to motor control commands
- Process: Capturing and writing direction and sonar values to a text file while manually driving the robot around an obstacle course
- Script and GUI written in Processing, which controls the robot, captures, and shows the direction and sonar values in real time
- Processing and Robot connected though Bluetooth Communication
- Amount of data points dependent on sonar sampling rate
- Limitation: only as good as the driver and consistency


45 Left/q	Forward/w	45 Right/e	U Turn /z
90 Left/a	Reverse/s	90 Right/d	
Stop/spacebar			
Direction: 0, Range1: 0,      Range2: 0,      Range3: 0,			

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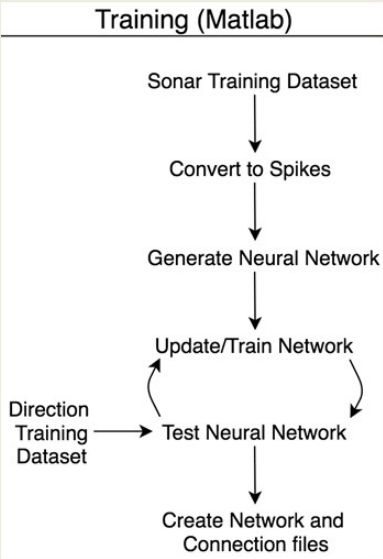


## Creating Trained CNNs



- **Input: Sonar and Direction training datasets**
- **Output: Network and Connection files**
- **Process of updating/training the neuron parameters and structure of the neural network using techniques, such as Backpropagation or EEDN learning (Energy Efficient Deep Neuromorphic Networks)**
- **The created network and connection files are imported onto TrueNorth and tested using the TrueNorth Communication Python script**

### Training (Matlab)




```

graph TD
    A[Sonar Training Dataset] --> B[Convert to Spikes]
    B --> C[Generate Neural Network]
    C --> D[Update/Train Network]
    D --> E[Test Neural Network]
    F[Direction Training Dataset] --> E
    E --> G[Create Network and Connection files]
    E --> D
    
```


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## What Went Wrong




- **Original idea: Design a robot that drives autonomously around an obstacle course using Neuromorphic Hardware and LIDAR unit stripped from a Neato XV-11 vacuum cleaner**
- **LIDAR unit's photodiode broke which caused a set back to sonar**
- **Limitations with serial data transfer and corruption bits**
- **IBM TrueNorth issues with open MPI and libraries**
- **Timing issues with TrueNorth and Arduino**


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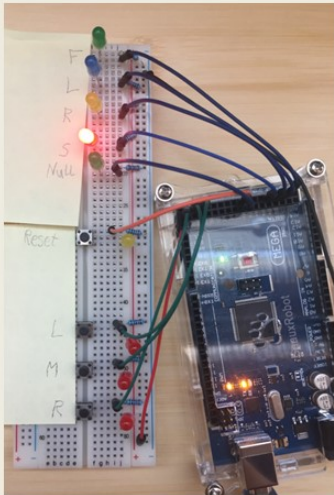
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## Current Progress



- **Completed**
  - ✓ Training robot and Real Data collection
  - ✓ Hardware and electronics aspects finished
  - ✓ Control Corelet
  - ✓ Communication TrueNorth Python script
  - ✓ Control Corelet Test with Buttons, LEDs, and TrueNorth – truth table Corelet created and successfully implemented on TrueNorth




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## Needs Work



- **Close to being completed**
  - Intermediate steps between TrueNorth Python and startup scripts
  - Demo of Collision Avoidance Robot with Control Corelet
- **Needs Work/Passing off to teammate Elizabeth**
  - Training networks
  - Testing and verification



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## Tests and Results






- Due to what went wrong, no data has been collected.
- Tests for data and results:
  - Performance Metrics:
    - Accuracy of the trained neural network
    - Power consumed by the TrueNorth (wattage and energy)
    - Speed of the neural network (how long it takes to obtain output response)
    - Temperature of the chip
  - How Performance Metrics are affected by:
    - Preprocessing input data
    - Using different spiking formats
    - Complexity of the network
    - Training
  - Compare against similar applications



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## What's Next? and Future Applications

- What's next for my project?
  - Expand to different or mix of hardware (e.g., phones, cameras, sensors, LIDAR, touch screen)
  - Apply different learning methods (e.g., supervised, unsupervised, online, offline, reinforcement, genetic algorithms)
  - Apply different architectures (e.g., TrueNorth, MrDANNA, DANNA)
- Future/Different Neuromorphic Applications
  - Autonomously driving - trail navigation, object avoidance, following robot
  - Image recognition – classifiers, phone application for determining objects, facial detection
  - Stability – balancing objects, helicopter, quadcopter, and camera stabilization



<https://www.seeedstudio.com/RPLIDAR-A2-The-Thrillnest-LIDAR-p-2607.html>



[https://commons.wikimedia.org/wiki/File:WMCH\\_Drone.jpg](https://commons.wikimedia.org/wiki/File:WMCH_Drone.jpg)

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## Frequently Asked Questions

**ARL**

- **Why use TrueNorth or Neuromorphic Computing Architectures instead of a small computer (e.g., Raspberry Pi)?**
  - Neuromorphic Computing is NOT a replacement but an alternative to tradition computing
  - SWP – Size, Weight, and Power
  - Raspberry Pi 3 consumes ~1 Watt idle, TrueNorth consumes ~100mW or less depending on the network
  - Prospective solution Memristor and CMOS application specific chips consuming ~1 mW or less depending on the network
  - Application specific chips – chips dedicated to do one job/process (e.g., autonomous driving, stability, image recognition)
- **This already exists. What makes this different?**
  - University of California, Irvine's Jeff Krichmar and research group has developed this type of application.
  - Differences: hardware, learning algorithms, and application

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## Conclusion

**ARL**

- **Neuromorphic computing is one way of going beyond Moore's Law.**
- **Main Idea of Project: Merging Neuromorphic Computing and robotics. As well, merging theory and simulation with real world applications.**
- **Overall Goal: Design a platform for testing Neuromorphic hardware and concepts.**
- **Short Term Goal: Design Collision Avoidance Robot using Neuromorphic Hardware.**

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## Acknowledgements

ARL



- I wish to acknowledge Manny Vindiola for being my mentor.
- Bryan Dawson, Jamie Infantolino, and Kevin Corder for helping with TrueNorth and various issues.
- Michael Barton, Ginny To, and ORISE for setting me up with this opportunity with ARL at APG.
- Kevin Wright and Andy Durkee for technical support.
- Elizabeth Klier helping design the neuromorphic aspects of the project.

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**ARL**



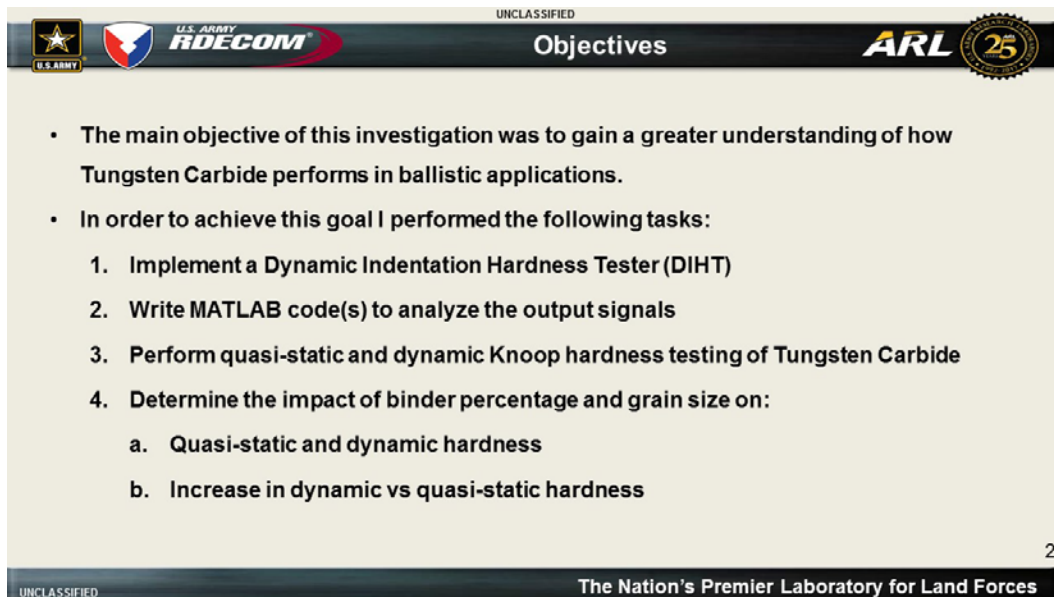
# Questions?

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## Luke A Hanner

I am a rising pre-junior at Drexel University in Philadelphia, Pennsylvania, where I am studying materials science and engineering. Last summer I participated in Drexel's Students Tackling Advanced Research (STAR) program, where I researched MAX Phase ternary carbides for 10 weeks. This is my first co-op experience and I began work on this project in May. In the future I hope to earn my master's degree and, possibly, a doctorate in materials science.





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## What is Tungsten Carbide?

ARL 25

- Tungsten Carbide (WC) is a cemented ceramic material composed of a hard WC main phase and a softer, more ductile metal binder phase.
  - The conventional binder is cobalt.
- WC is used in the M993 and M995 armor-piercing rounds (amongst others).
- WC is also used in industrial machining tools and applications.



M993 7.62mm Armor-piercing cartridge  
GlobalSecurity.org

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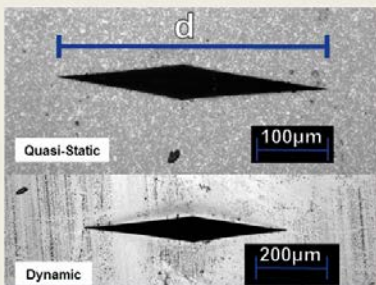
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## Indentation Hardness Testing

ARL 25

Indentation hardness is the measure of a material's resistance to plastic deformation.



Quasi-Static

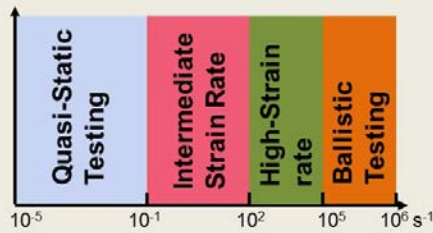
Dynamic

Quasi-Static Knoop Hardness (HK):

- 2kgf, 5kgf, and 10kgf loads
- $10^{-5} \text{ s}^{-1}$  strain rates

Dynamic Knoop Hardness (DHK):

- 30kgf - 110kgf load range
- $10^3 \text{ s}^{-1}$  strain rates



Quasi-Static Testing

Intermediate Strain Rate

High-Strain rate

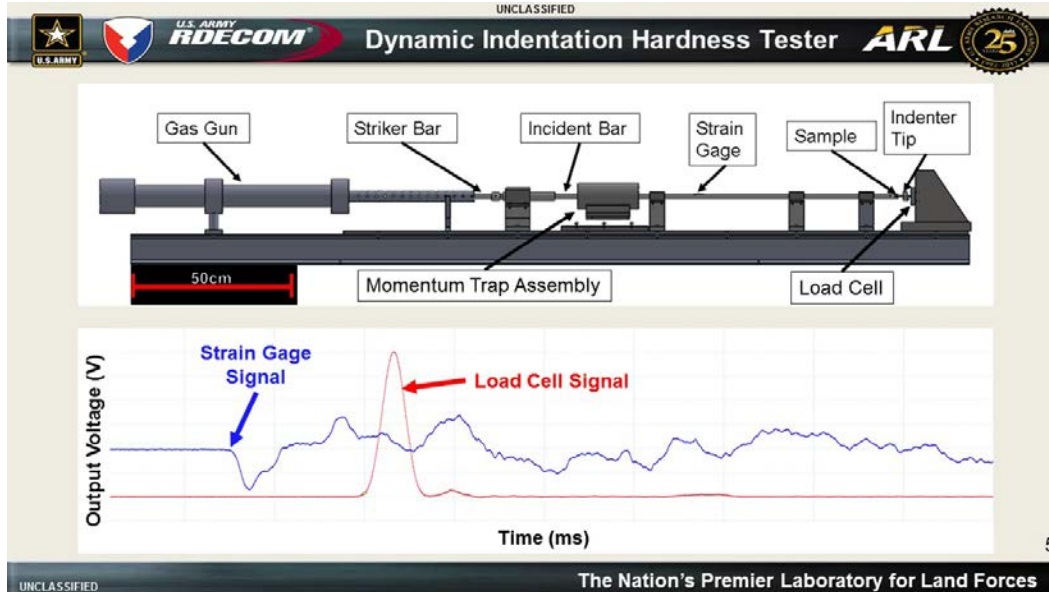
Ballistic Testing

$10^{-5}$   $10^{-1}$   $10^2$   $10^5$   $10^6 \text{ s}^{-1}$

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**MATLAB Code**

Analyzes raw strain gage and load cell signals to extract load and strain rate:

$$\varepsilon_i(t) = \frac{\text{Bridge Factor} \times \text{Strain Gage Signal}}{\text{Excitation Voltage} \times \text{Gage Factor} \times \text{Amplifier Gain}}$$
(Eq. 1)

$$\dot{\varepsilon}(t) = \frac{V}{d} = \frac{-C_0}{d} \varepsilon_i(t)$$
(Eq. 2)

$$P = \text{Load Cell Signal} \times \text{Charge Amplifier}$$
(Eq. 3)

$\varepsilon$  = Strain

$\dot{\varepsilon}$  = Strain Rate ( $\text{s}^{-1}$ )

$d$  = Indent Diagonal (mm)

$V$  = Indenter Velocity (m/s)

$C_0$  = Wave Speed in Bar (m/s)

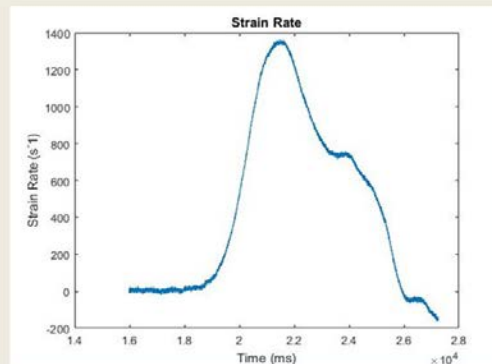
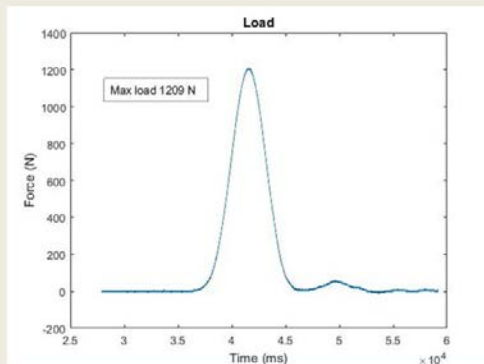
$P$  = Load (N)

$$HK = 0.014229 \times \frac{P}{d^2}$$

(Eq. 4)

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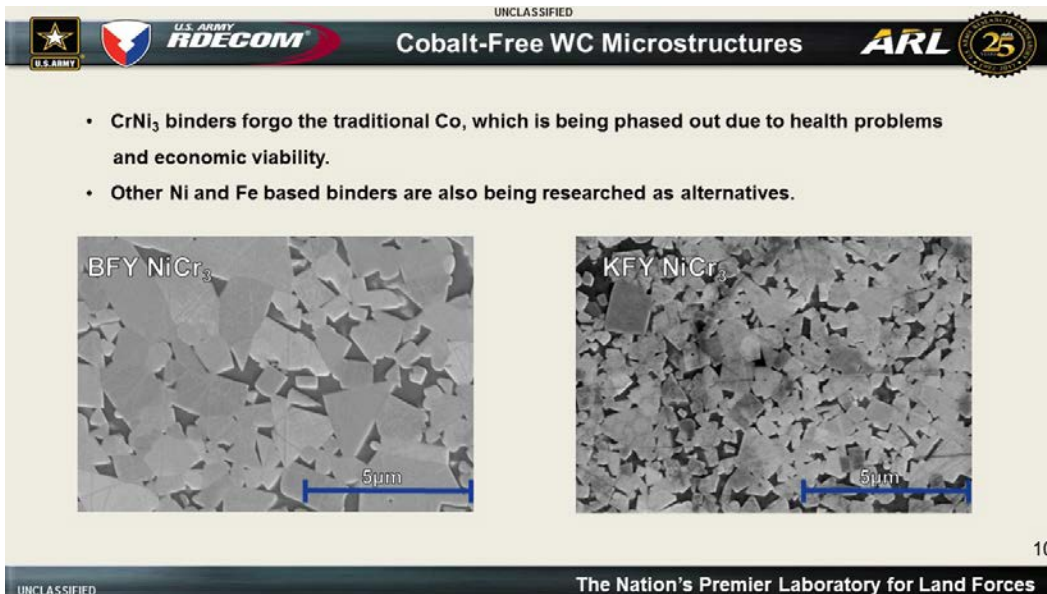
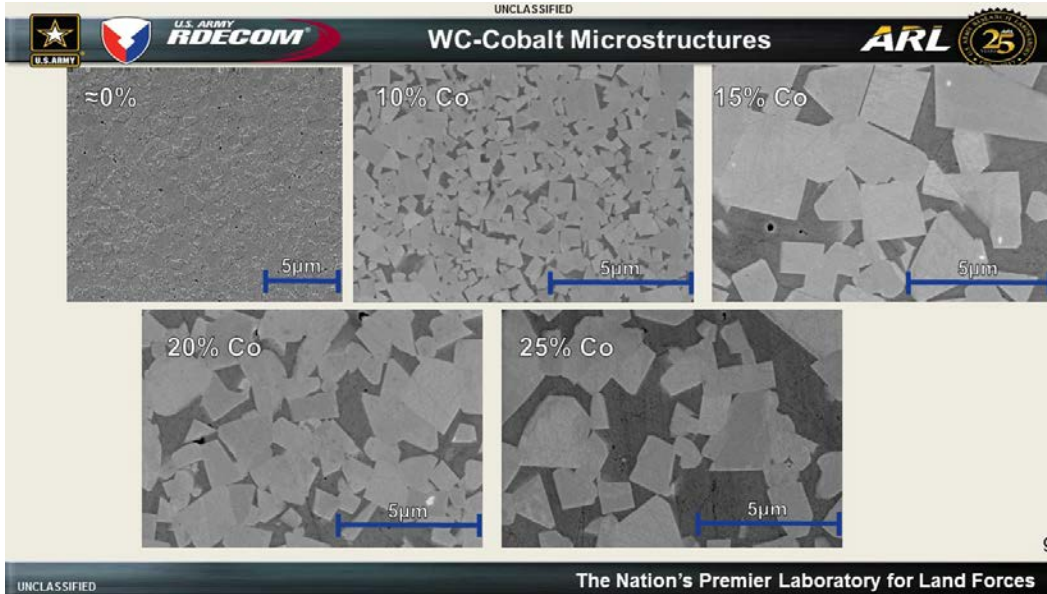
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- Seven different compositions tested
- Variations:
  - Binder material
  - Binder percentage
  - Grain size
- Commercial compositions used as benchmarks for future investigations of ARL systems

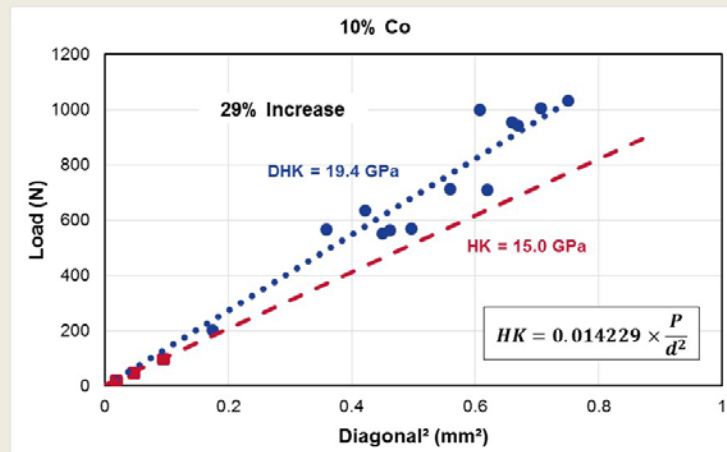
Material	Binder	Wt% Binder	Grain Size (μm)
Cercom <sup>®</sup> WC Binderless	N/A	≈0%	0.4
Kennametal S105	Co	10%	0.6
MPI <sup>†</sup> 15	Co	15%	1.7
MPI <sup>†</sup> 20	Co	20%	1.1
MPI <sup>†</sup> 25	Co	25%	1.5
Kennametal KFY	CrNi <sub>3</sub>	10%	0.6
Kennametal BFY	CrNi <sub>3</sub>	10%	0.9

<sup>\*</sup>Now part of CoorsTek, Golden, CO; <sup>†</sup>Materials Processing Inc.

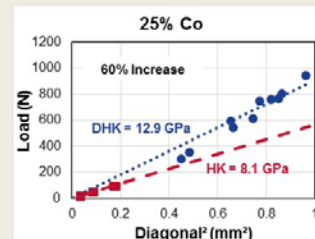
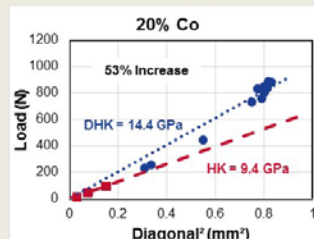
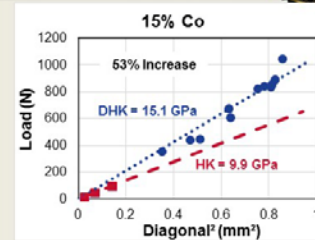
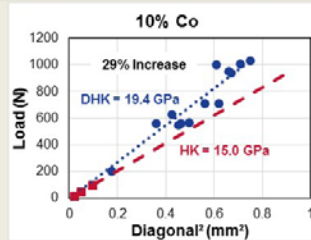
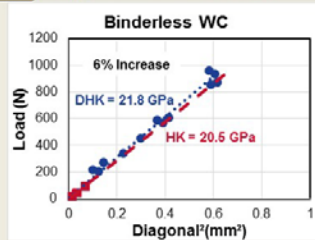
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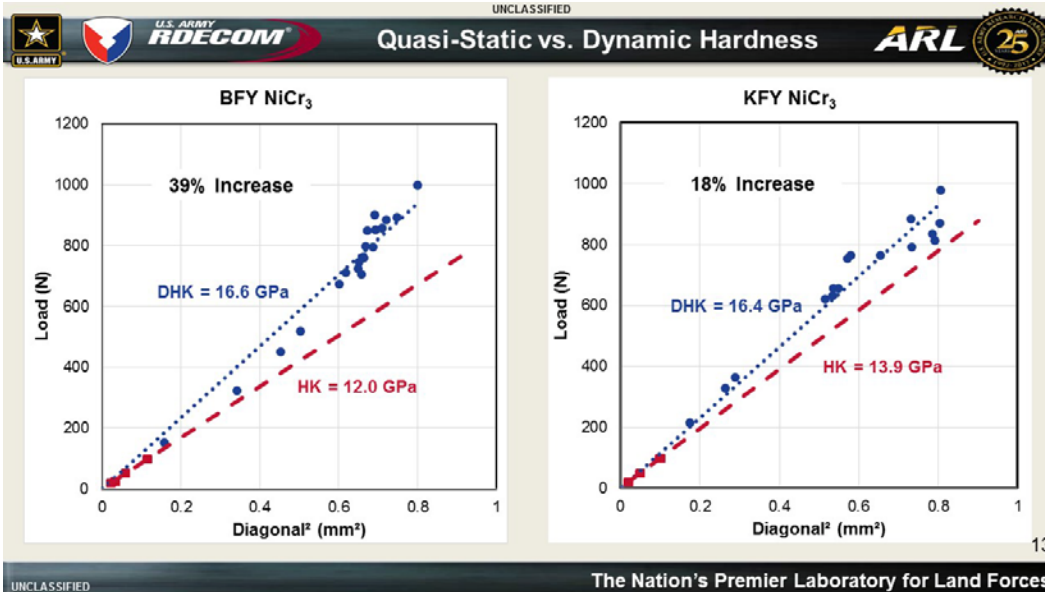


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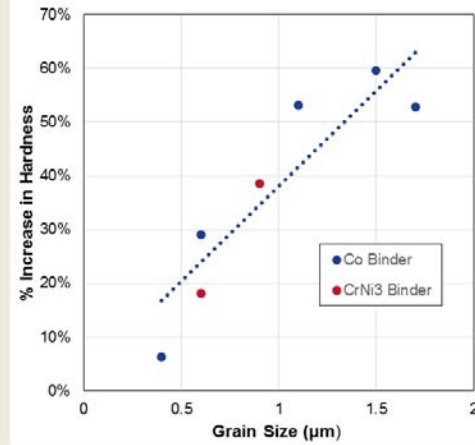
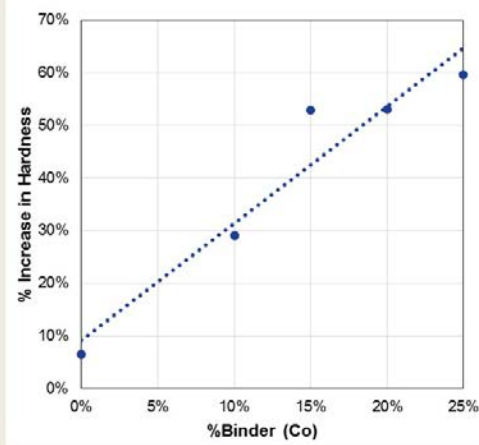
**Results from Indentation Testing**

NAME	Binder	Wt% Binder	Grain Size (μm)	Average HK (GPa)	Average DHK (GPa)	% Increase
Cercom <sup>®</sup> WC Binderless	N/A	≈0%	0.4	20.5	21.8	6%
Kennametal S105	Co	10%	0.6	15.0	19.4	29%
MPI <sup>†</sup> 15	Co	15%	1.7	9.9	15.1	53%
MPI <sup>†</sup> 20	Co	20%	1.1	9.4	14.4	53%
MPI <sup>†</sup> 25	Co	25%	1.5	8.1	12.9	60%
Kennametal KFY	CrNi <sub>3</sub>	10%	0.6	13.9	16.4	18%
Kennametal BFY	CrNi <sub>3</sub>	10%	0.9	12.0	16.6	39%

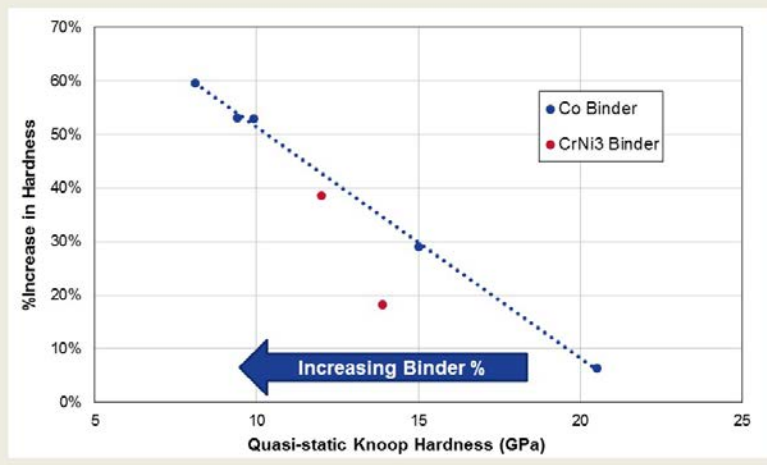
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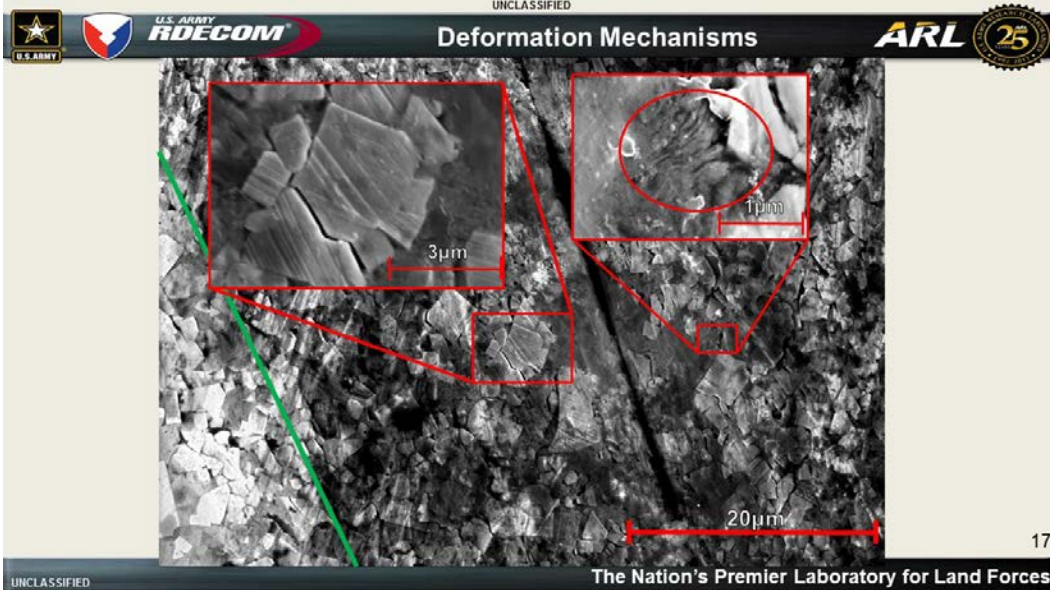
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## Twining in Cobalt Binder

- Cobalt has an HCP crystal structure with a low stacking-fault energy (SFE) and a limited number of slip systems.
- HCP structures with low SFE are highly susceptible to forming twins at high-strain rates.
- Twin boundaries act as barriers to dislocation motion, increasing hardness.

Hazell, P. J., et al.



[https://www.tl.uni-koeln.de/matwis/amat/def\\_en/kap\\_7/backbone/t7\\_1\\_1.html](https://www.tl.uni-koeln.de/matwis/amat/def_en/kap_7/backbone/t7_1_1.html)

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**Conclusions**





- Dynamic Knoop hardness is greater than quasi-static Knoop hardness
- As binder % and grain size increase, larger % increase in dynamic hardness.
- Linear relationship between quasi-static hardness and % increase of dynamic hardness
- Twinning in the Co binder a possible reason for these trends

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**Military Application and Future Work**



**Military Applications:**

- Bridges the gap between laboratory and ballistic performance of tungsten carbides
- Sets the benchmarks for future binders and materials used in armor-piercing rounds

**Future Work:**


- Further SEM and TEM investigation of twinning in HCP crystal structure of cobalt
- Test different cobalt-free WC systems (including ARL-developed materials)
- Investigate deformation mechanisms of alternate binder systems

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## Acknowledgments



- I would like to thank Dr. Jeffrey J. Swab and Dr. John J. Pittari III for their expertise and guidance
- As well as Steve Kilczewski, Howard Payne, Peter Loomis, and Geoff Xiao for moral support
- I would also like to thank CQL and The Academy of Applied Sciences for sponsoring my work






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## References





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2. Ramesh, Kalia T. "High rates and impact experiments." *Springer handbook of experimental solid mechanics*. Springer US, 2008. 929-960.
3. Subhash, G. "Dynamic Indentation Testing." *Materials Park, OH: ASM International, 2000*. (2000): 519-529.
4. Swab, Jeffrey J., and Jared C. Wright. "Application of ASTM C1421 to WC-Co fracture toughness measurement." *International Journal of Refractory Metals and Hard Materials* 58 (2016): 8-13.
5. Zhu, Y. T., X. Z. Liao, and X. L. Wu. "Deformation twinning in nanocrystalline materials." *Progress in Materials Science* 57.1 (2012): 1-62.

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Bio and Questions?



- From Bradenton, FL
- Rising pre-junior at Drexel University in materials science and engineering
- Captain of Drexel Men's Varsity Swimming and Diving
- I enjoy cooking and golf in my spare time







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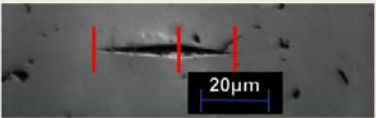
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Bad Indents








Good Indent



Asymmetric



Double Indent



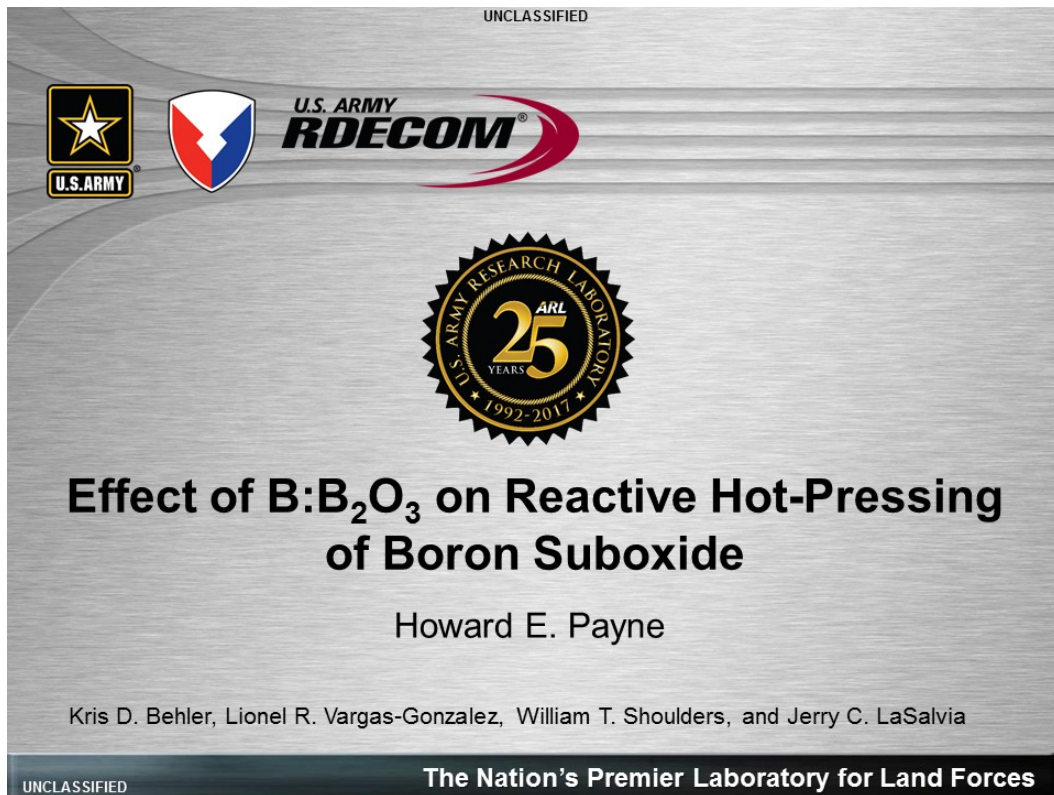
Heavy Spalling

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## Howard Payne

I am a third-year student at the Pennsylvania State University (Penn State), studying material science and engineering. Since my freshman year I have been working in a laboratory on campus, where we focused on binary and tertiary lead-based piezoelectrics under the advisement of Dr Messing. I will be returning to the CTMB branch in WMRD next year for a spring co-op to continue my research. After graduation, I am thinking of possibly going to graduate school to pursue a doctorate in materials or ceramics.



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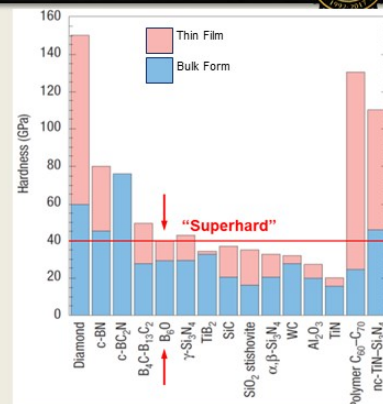
## BLUF

- Boron suboxide is an attractive armor ceramic
- Current process is very costly → synthesis powder then densify
- Combining synthesis and densification into a single-step (“Reactive Hot-Pressing”)
- Has the potential to decrease the cost of manufacturing dense bodies
- Discovered the importance of excess boron oxide on densification, phase purity, hardness, and hot-pressing issues

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## Background

- Armor applications
- High Hardness, Low density
- Current processing route is complex
- Boron suboxide synthesized at low pressures is oxygen-deficient ...  $B_6O_{1-x}$

nature.com

Courtesy of Dr. Behler

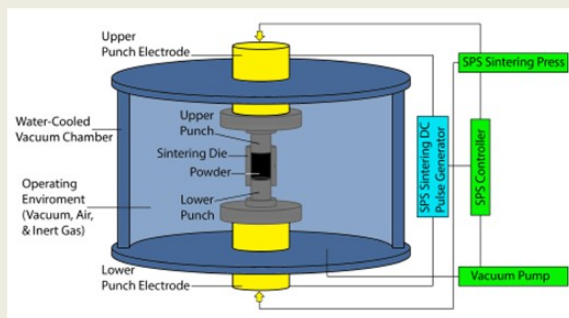
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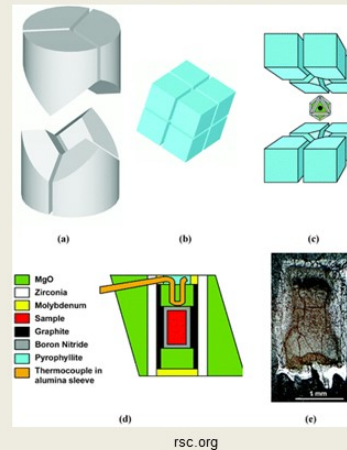
- SPS (Spark Plasma Sintering)
- Multi-anvil
- Hot-pressing with B<sub>6</sub>O powder

## SPS



calnanocorp.com

## Multi-anvil



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- Eliminate independent powder synthesis steps
- Might be able to lower the densification temperature
- Enhance industrial viability
  - Two less furnace steps needed
  - Less amorphous boron needed, highest cost component
- In-house production at ARL

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## Powder Processing

$$16B + B_2O_3 \rightarrow 3B_6O_{1-x}$$

- Powder**
  - $B_2O_3$ : 99.9% Noah Technologies
  - B(amorphous): 92.1-96% SB Boron Corporation
- Massed in ratios between 0-24 mass % excess Oxygen (O) in reaction
- Mixed on Lab Ram acoustic mixer for ~5 min
- Powders kept dry in vacuum oven

Powder (Mass % O)	$B_2O_3$ (g)	B (g)
Stoichiometric	3.1565	7.8440
6.8% excess O	4.2422	6.7581
10.2% excess O	2.8217	2.1786
12.3% excess O	6.9714	8.0276
23.7% excess O	9.4668	5.5341

**Step 1:**  
React boron at 400-500°C in air, wet Ar, OR  $O_2/Ar$  mix

**Step 2:**  
React  $B(B(OH)_3)$  core/shell at 1400°C in dry Ar

$6B + 1/2 O_2 \rightarrow 16/3 B + 1/3 B_2O_3 \rightarrow B_6O$

**One Step:**  
Mix Boron with Boron oxide, react during Hot-Press

$16B + B_2O_3 \rightarrow B_6O$

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## Reactive Hot-Pressing

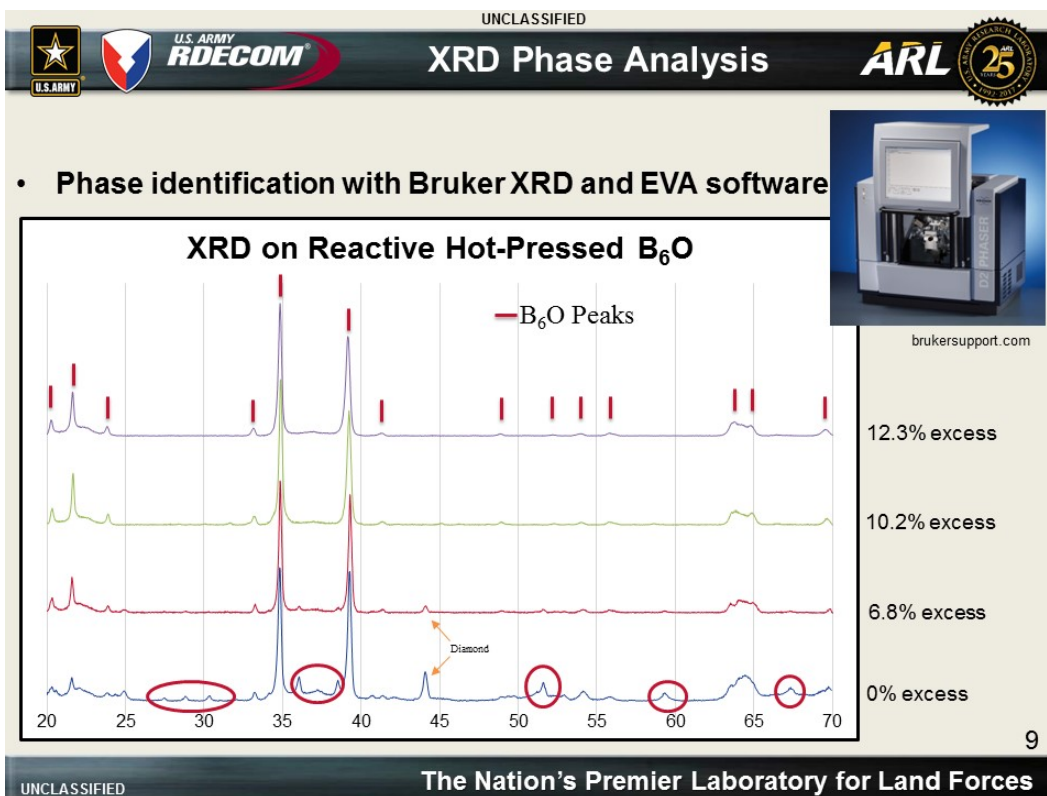
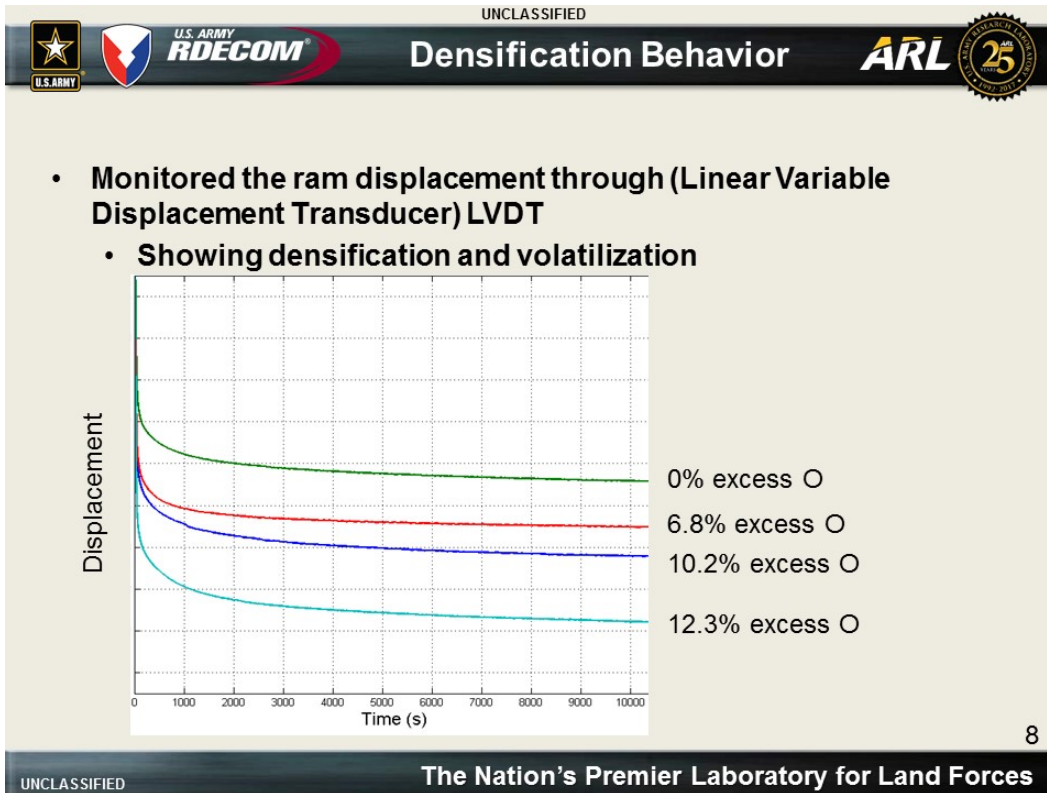
- Followed typical densification profile as previous hot-pressing
- Tested 0-24 mass % excess O
- 6100 lbf on 1-inch Die (~53.6 MPa) applied at 3h hold
- BN coating on graphite die

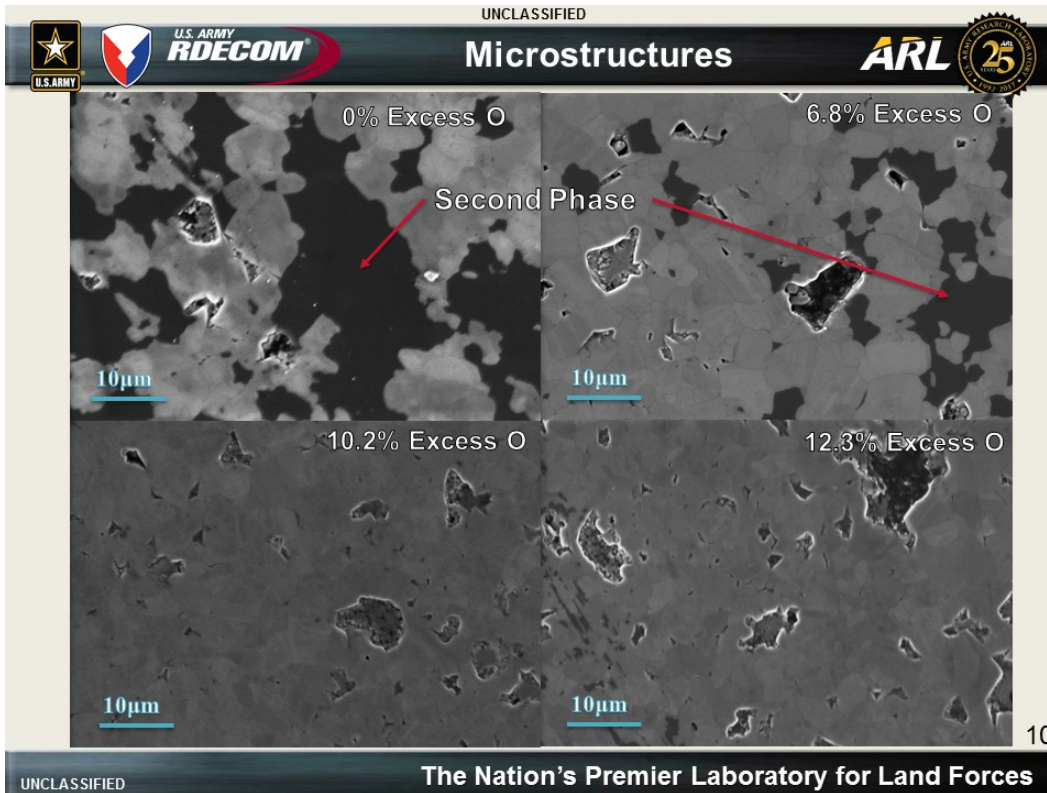
**Temperature Profile**

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## Hardness/Densities

- Hardness: Knoop with 2-kg load, manual indenter
- Density: He pycnometer

Sample	HK (GPa)	Density (g/cc)
Stoichiometric	18.5 ± 0.4	2.462
6.8% excess O	19.8 ± 0.8	2.556
10.2% excess O	18.4 ± 0.6	2.546
12.3% excess O	14.9 ± 1.7	2.490
Coorstek – HIP <small>Courtesy of Dr. Behler</small>	18.9 ± 0.5	2.56

$$HK = 0.014229 \frac{P}{d^2}$$

P: Load (N)  
D: Length on Long Diagonal (mm)

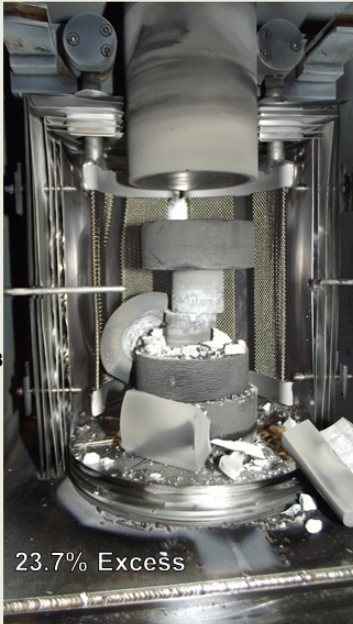
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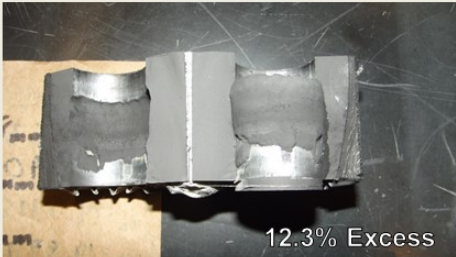
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## Difficulties

- Reaction of powders with die
  - Learning better methods of coating die with BN
- Hygroscopic powders, need to keep powders in glove box
- Die failure
  - Affected 23.7% test
  - Shows issues with too much  $B_2O_3$



23.7% Excess



12.3% Excess

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## Conclusion/Future Research


- For reactive hot-pressing a composition of 6.8-10.2 mass% excess O should be used
  - XRD Data
  - Elimination of 2<sup>nd</sup> phase in microstructure
  - Highest hardness and density values achieved
- Additives effect on Boron Suboxide
  - Hardness, fracture toughness, density
  - Will the thermodynamics of reaction have any effect?
  - Possible: yttria, silica, mullite, rare earths, etc.
- Redo study with better controlled powder chemistry



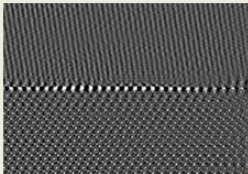
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=



B

$B_2O_3$

$Y_2O_3$

Courtesy of Dr. Behler





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  **Acknowledgements**  


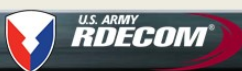


- I would like to thank both my official and unofficial mentors Dr. Lionel Vargas-Gonzalez, Dr. Kris Behler, and Dr. William Shoulders.
- I am also thankful to Dr. Jeffery Swab, Academy of Applied Science, and the Qualified College Leaders program for the opportunity to be at ARL this summer.
- For moral support: Dr. Jerry LaSalvia, Mr. Steve Kilczewski, Mr. Luke Hanner, and Mr. William Costakis.

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  **Citation**  

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H. Hubert, B. Devouard, *Letters to nature* 1998, 391, 376.

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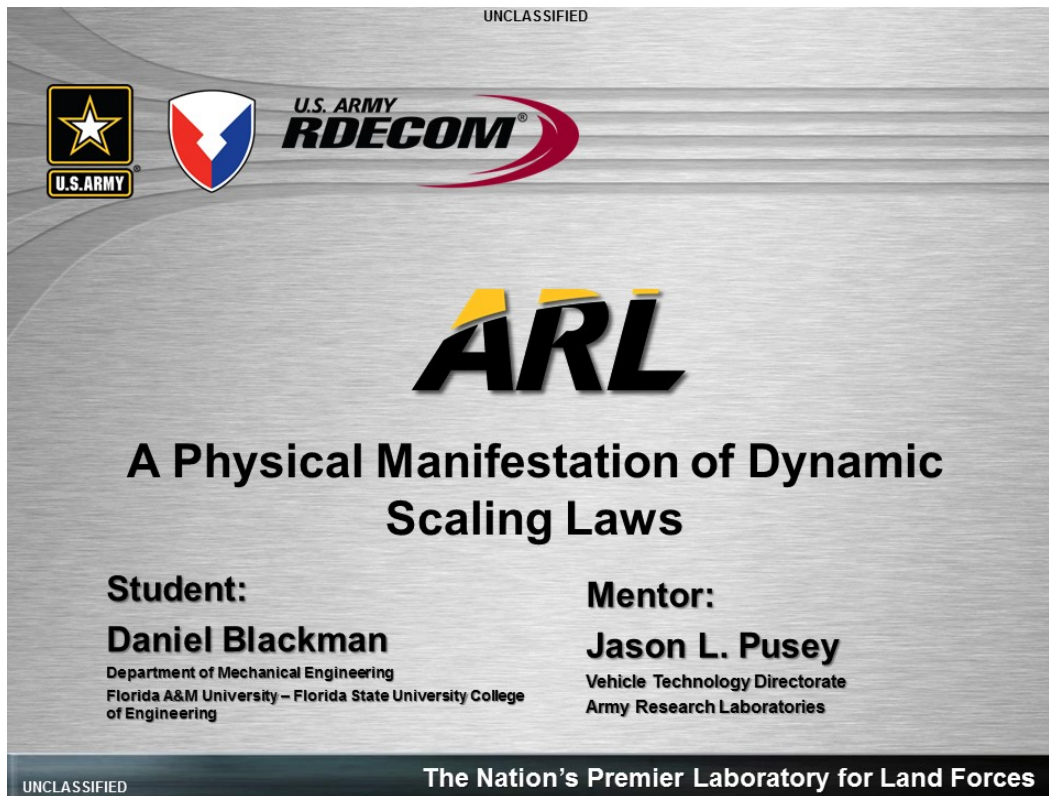
## **Graduate Presentations**

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## Daniel Blackman

Daniel Blackman is a third-year doctoral student in mechanical engineering at Florida State University under the direction of Dr Jonathan Clark. He received dual bachelor's degrees in biochemistry and physics from Edinboro University, and his master's degree in biomedical engineering from Cornell University. His past research experiences span organic chemistry, metallurgy, biophysics, biomechanics, and bio-inspired robotics. His current research focuses on this last area, specifically relating to the design, dynamics, and control of legged robotic systems. This summer, he focused on the challenges associated with designing these legged systems at different sizes while maintaining the dynamic capabilities required by the armed forces. After completing his doctorate in mechanical engineering, Daniel intends to pursue a medical degree and/or postdoctoral research in the fields of biomechatronic prosthetics and therapeutic exosuits.



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## Why Build It Bigger?

- Surface manipulation
  - Desks, doors, drawers, etc
- Optempo Speeds
  - (operations tempo)
- Soldier accessibility

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## OPTEMPO (Operations Tempo)

- Wheels vs Legs

**MIT**  
Massachusetts Institute of Technology

**Autonomous Running Jumps Over Obstacles in the MIT Cheetah 2**

Hae-Won Park, Patrick Wensing, and Sangbae Kim

MITCHEGHE BIOMIMETIC ROBOTICS LAB

# RHex

UPenn RHex

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## Scaling Robotic Systems

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## Background: Dynamic Scaling

TABLE II

SCALE FACTORS FOR SYSTEM VARIABLES OF DYNAMICAL, LEGGED MODELS

Parameter	Scale Factor	General Case	Constraint 1 <sup>1</sup>	Constraint 2 <sup>2</sup>	Constraints 1 <sup>1</sup> and 2 <sup>2</sup>
Length	$\alpha_L$	$\alpha_L$	$\alpha_L$	$\alpha_L$	$\alpha_L$
Mass	$\alpha_m$	$\alpha_F \alpha_L^{-1} \alpha_T^{-2}$	$\alpha_F$	$\alpha_L^4 \alpha_T^{-2}$	$\alpha_L^3$
Stiffness	$\alpha_k$	$\alpha_F \alpha_L^{-1}$	$\alpha_F \alpha_L^{-1}$	$\alpha_L^3 \alpha_T^{-2}$	$\alpha_L^2$
Damping	$\alpha_b$	$\alpha_F \alpha_L^{-1} \alpha_T$	$\alpha_F \alpha_L^{-1/2}$	$\alpha_L^3 \alpha_T^{-1}$	$\alpha_L^{5/2}$
Frequency	$\alpha_\omega$	$\alpha_T^{-1}$	$\alpha_L^{-1/2}$	$\alpha_T^{-1}$	$\alpha_L^{-1/2}$
Gravity	$\alpha_g$	$\alpha_L \alpha_T^{-2}$	1	$\alpha_L \alpha_T^{-2}$	1
Touch-Down Velocity	$\alpha_v$	$\alpha_L \alpha_T^{-1}$	$\alpha_L^{1/2}$	$\alpha_L \alpha_T^{-1}$	$\alpha_L^{1/2}$
Touch-Down Heading	$\alpha_\delta$	1	1	1	1
Touch-Down Leg Angle	$\alpha_\beta$	1	1	1	1

\* Constraint 1: Gravity is scale independent ( $\alpha_g = \alpha_T^{-2}$ ).

\* Constraint 2: Density is constant ( $\alpha_m = \alpha_L^3$ ).

\* The gravity scale factor is equivalent to the acceleration scale factor, though it is not specifically addressed herein.

Miller & Clark (2015)

- Robotic advantages
  - Material selection
  - Planetary constraints

Parameter	RHex	Scaled to Edubot*	Edubot*
Body Length (m)	0.51 <sup>1</sup>	0.37	0.36
Leg Length (m)	0.16 <sup>1</sup>	0.115	0.115
Mass (kg)	7.5 <sup>1</sup>	3.2	3.2
Leg Stiffness (Nm <sup>-1</sup> )	1900 <sup>1</sup>	1130	960
Speed (ms <sup>-1</sup> )	2.7 <sup>1</sup>	2.29	2.25
Stride Frequency (s <sup>-1</sup> )	4.2	4.95	5.25
Froude Number (—)	4.67	4.67	4.49
Strouhal Number (—)	4.02	4.02	3.86
Specific Resistance (—)	0.84 <sup>1</sup>	0.84	0.51

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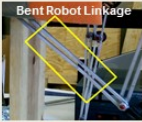
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## Plan of Action

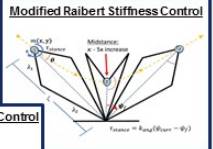
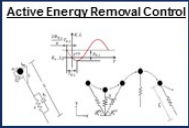
### 1. Design at the Scale of Interest





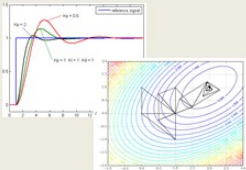
### 2. Scaling limitations



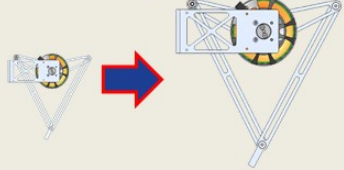
### 3. Controller Development

### 4. Controller and Physical Design Optimization

### 5. Dynamic Scaling of Controllers




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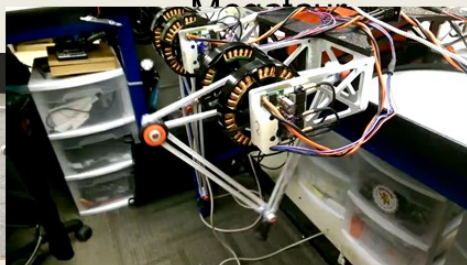
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## 1. Design at Scale: Minitaur

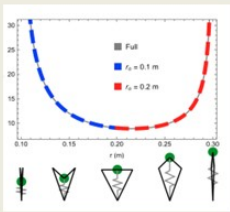
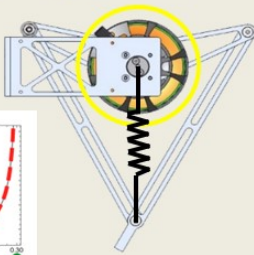
### Minitaur



Physical Parameters	
Parameter	Value
Mass	5kg
Length	0.4m
Width	0.22m
Max Height	0.3m



- Unique direct-drive system (5-bar)
  - High speed regions
  - Localization of motor mass
  - Mechanical compliance

Kenneally and Koditschek (2015)

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## 1. Design at Scale: Thumper

**Thumper specs:**

Upper limb: 0.15 m

Lower limb: 0.3 m

Total mass, without boom: 2.98 kg

Total mass, on boom: 3.467 kg

Boom length (Radius of rotation): 1.38 m

Boom offset + Height of pivot:  $0.0758 + 0.22 = 0.2958$  m

**Motor specs: U10 plus**

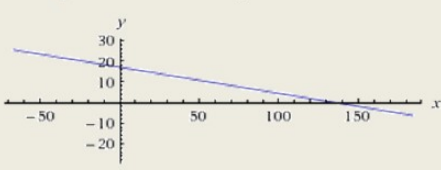
Motor (Torque) Constant  $K_t$ : 0.119 Nm/A

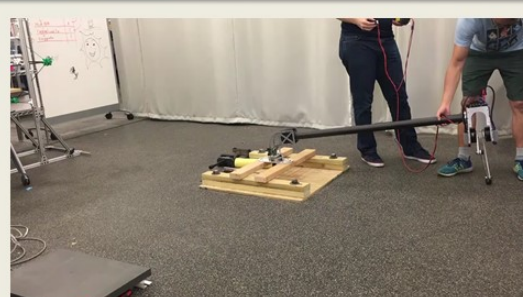
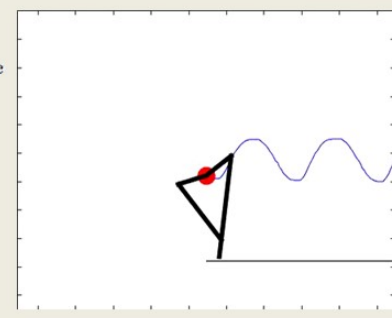
Motor Resistance  $R_m$ : 0.112 Ohm

Motor back emf constant  $K_e$  (same as torque constant): 0.119 V/(rads/s)

According to Avik, since the slope of the motor torque-velocity looks very low, we could neglect the effect of back emf. The curve is

Volt =  $(R_m/k_t) * \text{Torque} + k_e * \text{speed}$ ; or  $16 = (0.112/0.119) * \text{Torque} + 0.119 * \text{speed}$ . It looks something like this



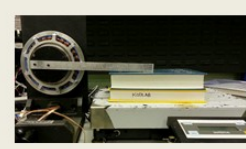
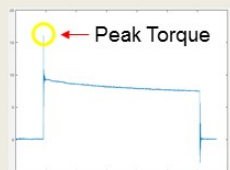
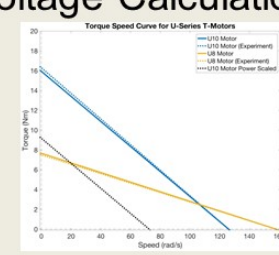
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## 2. System Limitations: Power Theory

### Force Plate Measurement Confirms Voltage Calculation


→

→


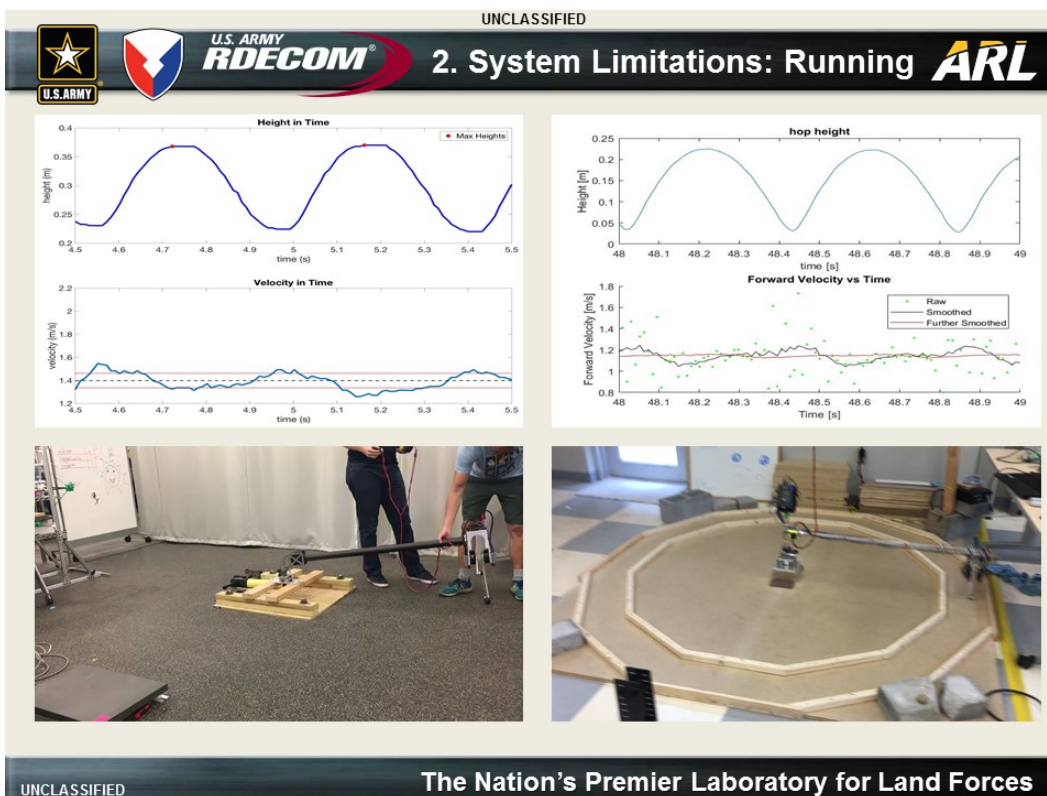
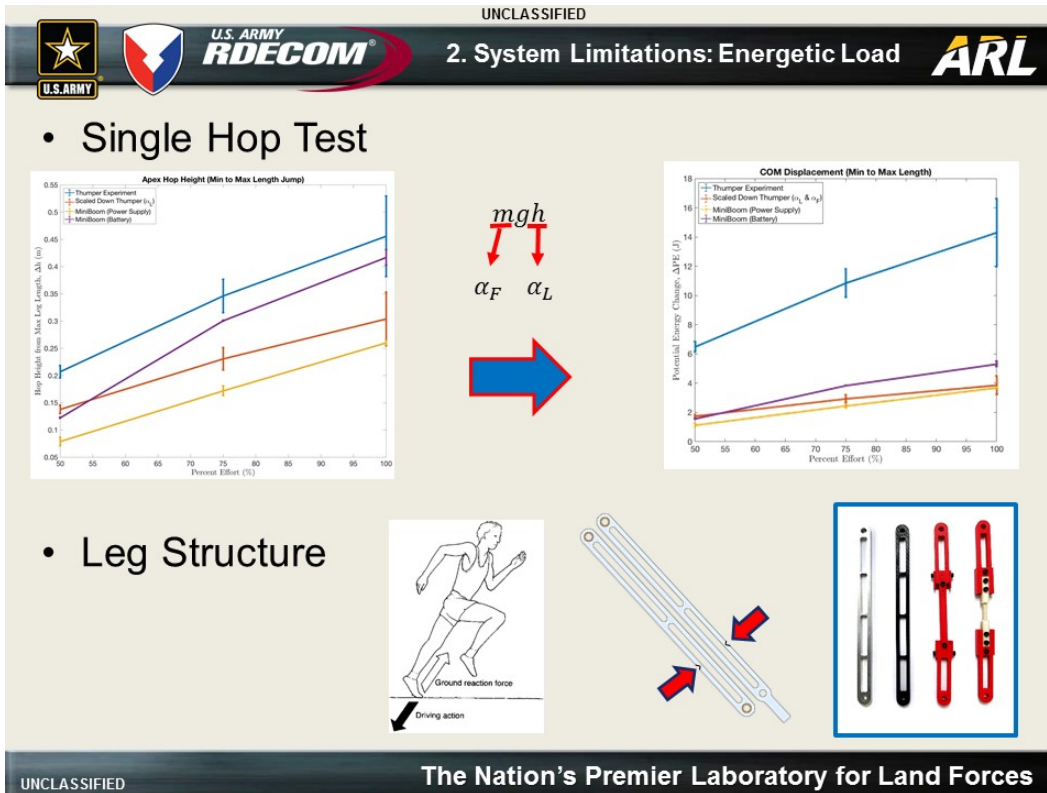
**Scaling Motor**

- Calculate U10 Power:  $P = \frac{V^2}{R_m}$  or  $P = \tau_{stall} \omega_{NL}$
- Scaled Power:  $P_{scaled} = \alpha_P P = \frac{\alpha_F \alpha_L^2}{\alpha_T^3} P = \alpha_F \sqrt{\alpha_L} P$
- Use U10 values ( $k_e, k_t, R_m$ ):  $V_{scale} = \sqrt{P_{scale} R_m}$

$\tau_{stall} = \frac{k_t V}{R_m}$ 
 $\omega_{NL} = \frac{V}{k_e}$

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3. Controller Development: Raibert **ARL**

- Raibert SLIP-based Controller
  - Assume pogo stick motion (**S**pring **L**oaded **I**nverted **P**endulum)
  - Apply thrust in decompression phase
- Modifications
  - Stiffness increase by a factor (2<sup>nd</sup> half of stance)
  - Touchdown angle modulation
  - Hip rotation torque throughout stance

$$v_{avg} = \frac{\sum_{j=1}^T v_x(j)}{k_r c_{rate}}$$

$$\kappa = 5\kappa$$

$$\tau_{stance} = k_a(\psi_{curr} - \psi_f)$$

$$\psi_{TD(n+1)} = \psi_f + k_v v_{avg}$$

MIT Raibert Hopper

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3. Controller Development: AER **ARL**

- Raibert SLIP-based Controller
  - Assume pogo stick motion (**S**pring **L**oaded **I**nverted **P**endulum)
  - Apply thrust in decompression phase
- Modifications
  - Touchdown angle adjustment
  - Energy removal through nominal leg length adjustment

$$\beta_{n+1}^{TD} = \beta_n^{LO} + c(\beta_n^{TD} - \beta_{des}^{TD})$$

$$l_0 = l_{nom} - l_{dev} \sin\left(\frac{\pi t}{t_{des}}\right)$$

FSU Boom Leg

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**Path Forward**

## 4. Controller and Physical Design Optimization

## 5. Dynamic Controller Scaling

**Minitaur**

➔

**Megataur**

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**Conclusion Summary**

### 1. Design at the Scale of Interest

### 2. Scaling limitations

$P_{scaled} = \alpha \sqrt{\rho/L} P$

### 3. Controller Development

### 4. Controller and Physical Design Optimization

**Old Bearings**

**New Bearings**

### 5. Dynamic Scaling of Controllers

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## Acknowledgements



- Thank to VTD-ARL for hosting me this summer
- Special thanks to:
  - **Matthew Davis** for breakaway leg design
  - **John Nicholson** and **Wei-hsi Chen** for design and refinement of controllers and implementation on physical platforms
  - **Jason L. Pusey** for inspiring and motivating me throughout the summer as my mentor here at ARL
  - **Harris Edge** for his leadership and guidance in VTD
  - **RCTA** and **Stuart Young** for funding my research both at FSU and throughout this summer program

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## • Funding Source

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## References



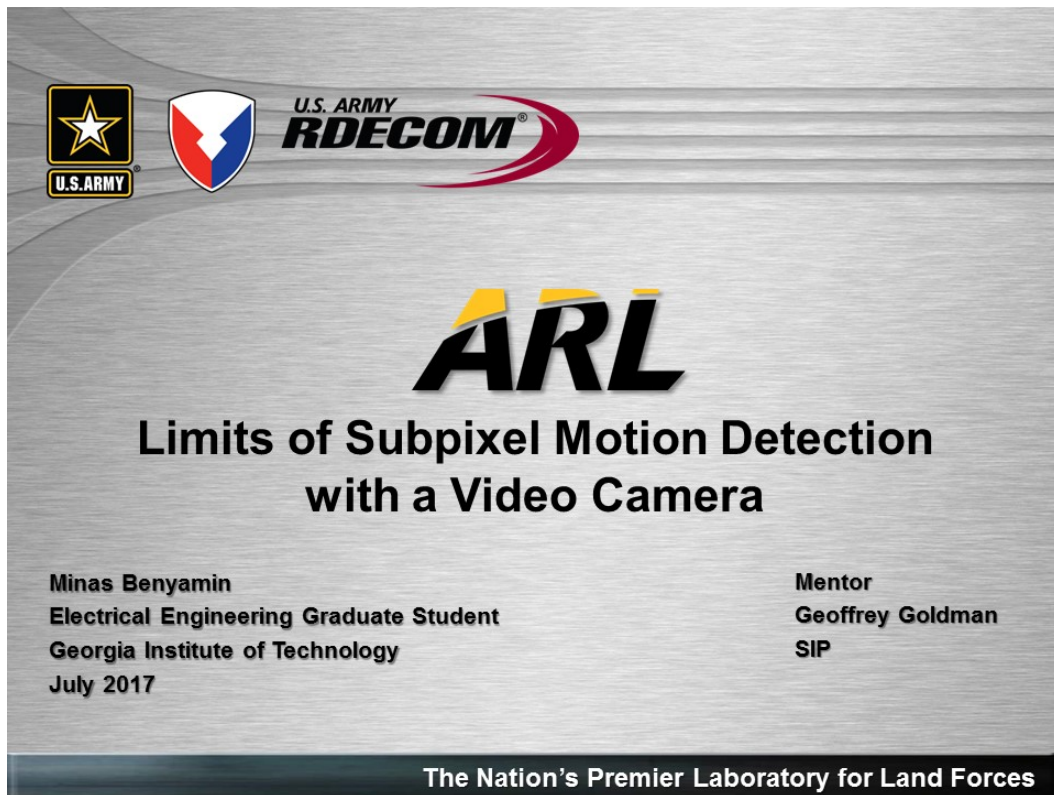
- Blackman, D.J., Nicholson, J.V., Ordonez, C., Miller, B.D., and Clark, J.E. "Gait development on Minitaur, a direct drive quadrupedal robot," in SPIE Defense+Security Conference. pp. 98370I-98370I-15, International Society for Optics and Photonics, 2016.
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## **Minas Benyamin**

Minas Benyamin is a graduate of the University of Maryland, Clark School of Engineering. His undergraduate degree was in electrical engineering with a minor in mathematics. I am pursuing graduate studies at the University of Georgia Tech in Atlanta, Georgia, majoring in signal processing and controls. My focus is on signals with experience in radar, computer vision, and machine learning. In the future I see my research as designing robotics with adaptive control systems managed via imaging and other sensor systems.





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## Outline

### Summer Objective: Determine practical limits of subpixel motion detection using a video camera

- Introduction
  - Motivation
  - Experimental Setup
- Signal Processing
  - Outline of Algorithm
  - Edge Finding
  - Subpixel Detection
  - Noise Statistics and Estimation Limits
- Results
  - ROC Curves
  - Simulated
  - Measured
- Conclusion



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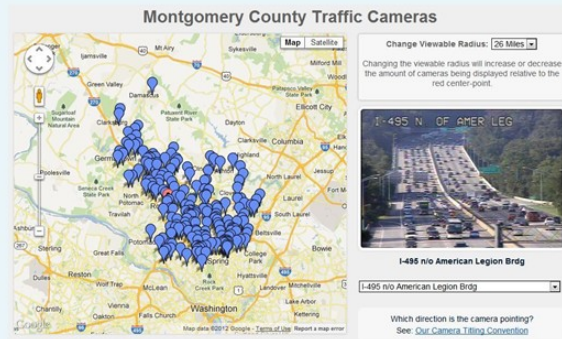
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## Motivation and Background

- Video cameras are ubiquitous
- Objects such as paper, clothing, windows, and thin walls move in response to sound waves
- Acoustic data can be extracted from video feed of these objects
- Many environments often pose limitations to acquiring audio
- Interest in analyzing audio spectra of target of interest



A. Davis, M. Rubinstein, N. Wadhwa, G. Mysore, F. Durand, W. T. Freeman, "The visual microphone: Passive recovery of sound from video", *ACM Trans. Graph.*, vol. 33, no. 4, pp. 79:1-79:10, 2014.



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## Experimental Setup

- Conducted in ARL Anechoic Chamber to reduce noise
- Measured a motor actuated rod
- Collected moving and static data



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## Moving Target - make better



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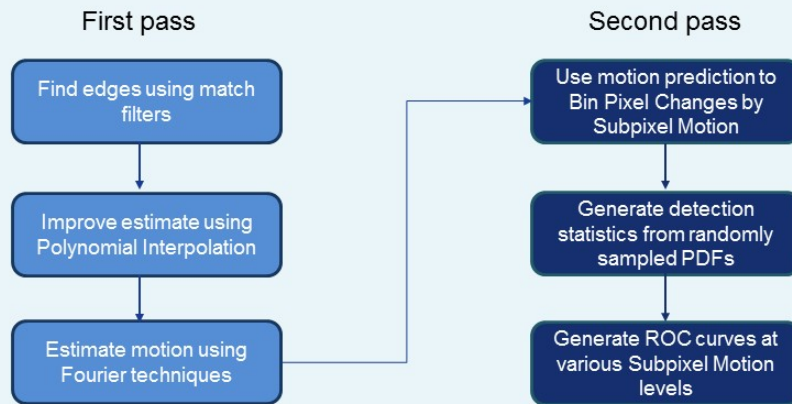
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## Signal processing



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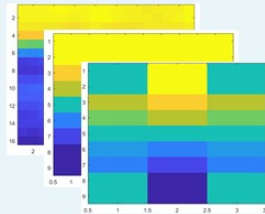
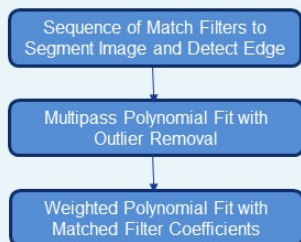
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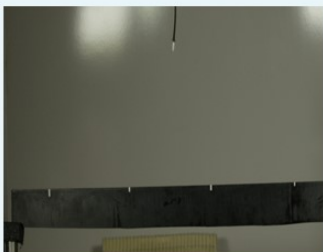
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## Edge Detection

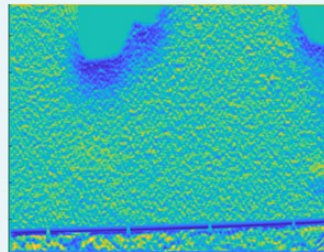


$$p = \frac{(V^T \cdot W \cdot V)}{V^T \cdot W \cdot \vec{x}} - \text{Polynomial}$$
$$V = [1 \ y \ y^2 \ \dots] - \text{Vandermonde}$$
$$W - \text{Weight Array}$$

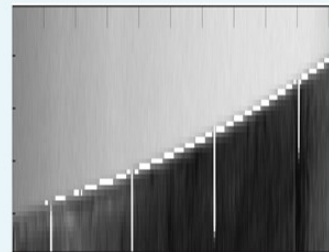
Image of rod



Matched filter output



Detected edge



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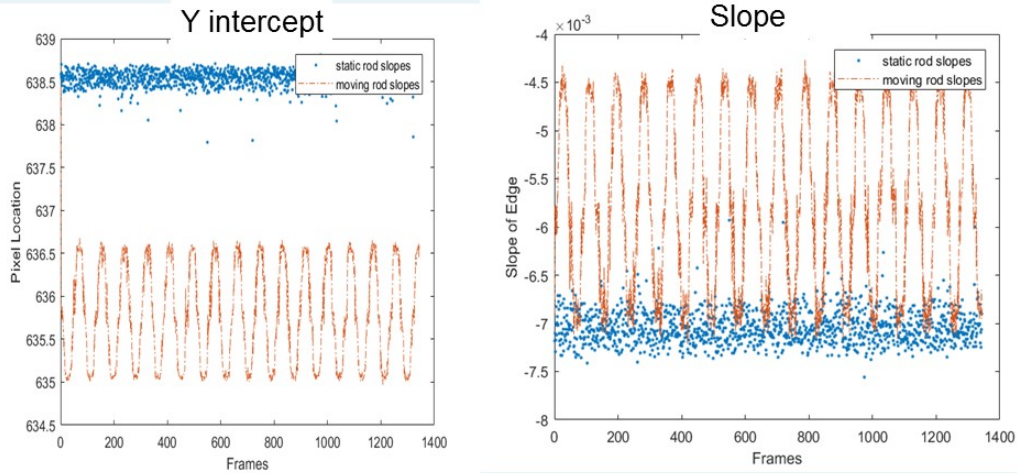
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## Polynomial coefficients versus frame #



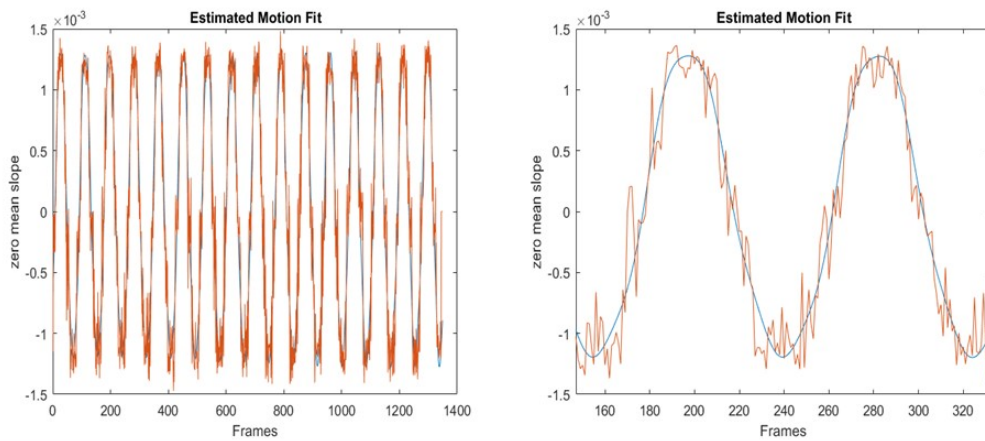
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## Fourier Model Fitting



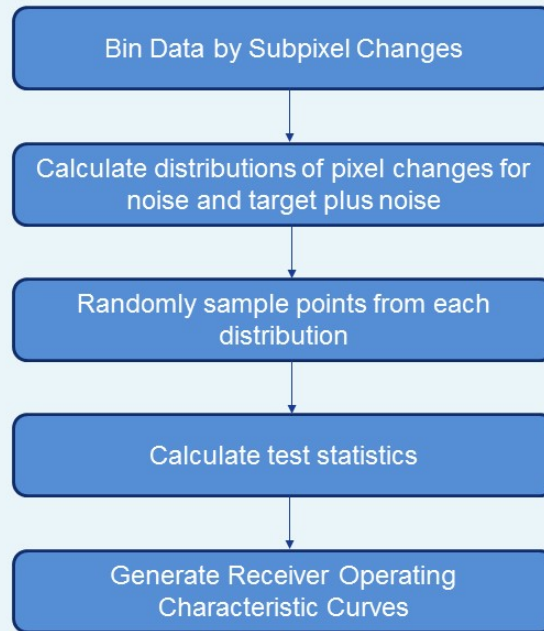
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## Subpixel Detection Algorithm



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## Detection Algorithms

- Binary Detector
- $I$  Observations

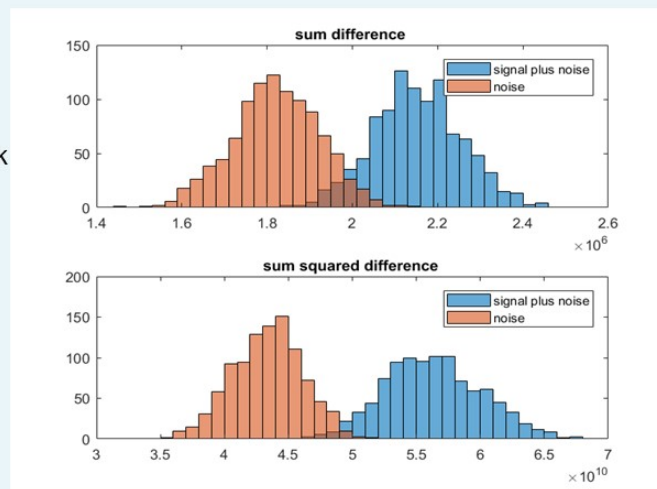
- $H_1$ : No Pixel Shift
- $H_2$ : Pixel Shift

Test Statistics – need work

$$\varphi_1 = \sum_i |diff_i|$$

$$\varphi_2 = \sum_i |diff_i|^2$$

Results for  $I=100$  Pixels



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## Noise Distribution Digital Camera

- Thermal noise (Dark current)
  - Thermal noise power =  $4kTBR$
  - Capacitor reset power =  $KT/C$
  - additive Gaussian
  - can be bigger in blue channel due to increased amplification
- Impulse noise (salt and pepper noise)
  - ADC errors
  - bit errors
  - photo diode leakage current for slow shutter speeds
- Shot noise – discrete nature of particles
  - thermal generation within a depletion region
  - statically quantum fluctuations in number of photons
  - Poisson distribution with rms level proportional to square root of image intensity
  - $P(X=k) = \lambda^k e^{-\lambda} / k!$  where  $\lambda = E(X) = \text{Var}(X)$
  - thermal generation within a depletion region
- Quantization noise
- Periodic noise
  - 60- or 120-Hz noise
- Readout noise
  - CCD: 3-8 electrons
  - CMOS: 2-4 electrons



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## Cramer-Rao Lower Bound for Estimating Subpixel Shift



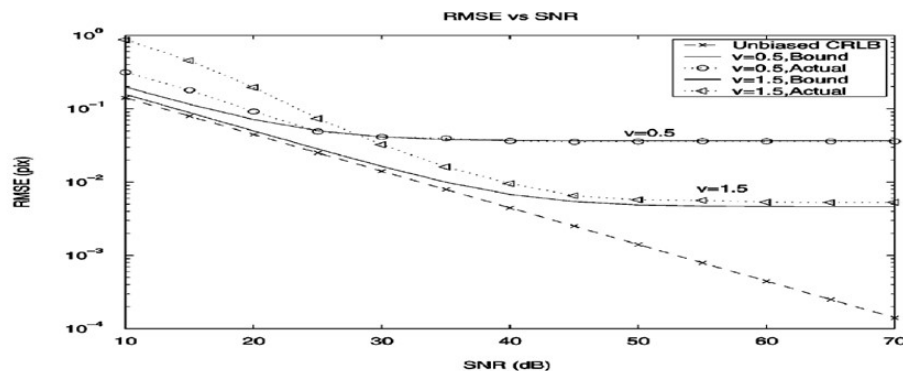
$$\text{mse}(\phi) \geq J(\phi)^{-1}$$

$$J(v) = \begin{bmatrix} a_1 & a_2 \\ a_2 & a_3 \end{bmatrix}$$

$$a_1 = \sum_{m,n} f_x^2(m - v_1, n - v_2)$$

$$a_2 = \sum_{m,n} f_x(m - v_1, n - v_2) f_y(m - v_1, n - v_2)$$

$$a_3 = \sum_{m,n} f_y^2(m - v_1, n - v_2).$$



D. ROBINSON, P. MILANFAR, "Fundamental Performance Limits in Image Registration", *IEEE Trans. Image Process*, vol. 13, no. 9, pp. 1185-1199, 2004.

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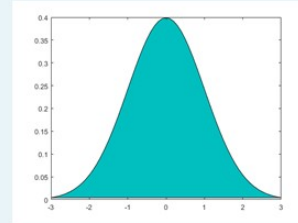
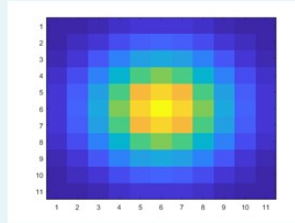
## Rod Simulation



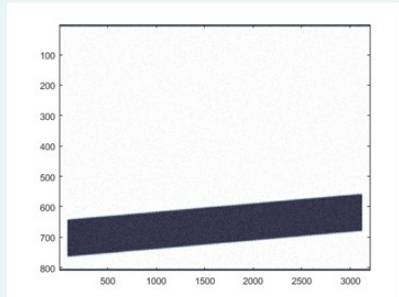
Simulate moving rod with Simple  
Sinusoidal Motion

Convolve images with simulated  
PSF Kernel & add Gaussian Noise

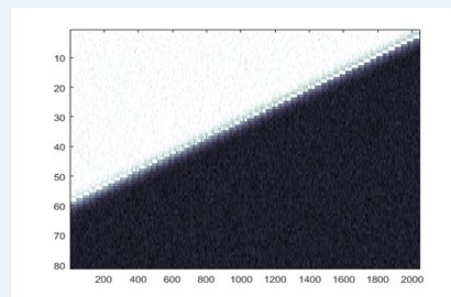
Run through Two-Pass Processing  
Algorithm



Simulated Rod



Rod Edge Detection



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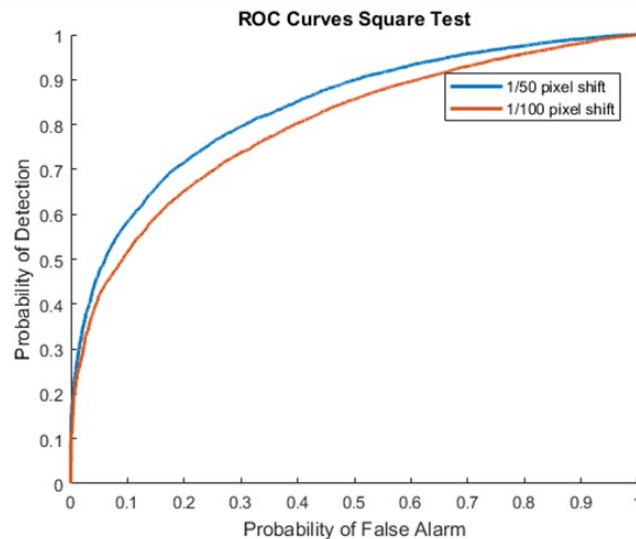
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## Simulation Roc Curves

Detection Algorithm:  
- Squared Difference  
Number of Pixels:  
- 25  
Number of Samples:  
- 10,000  
Noise:  
- Gaussian  
- SNR = 37 dB  
PSF:  
- Gaussian Kernel



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## Measured Roc Curves

Detection Algorithm:

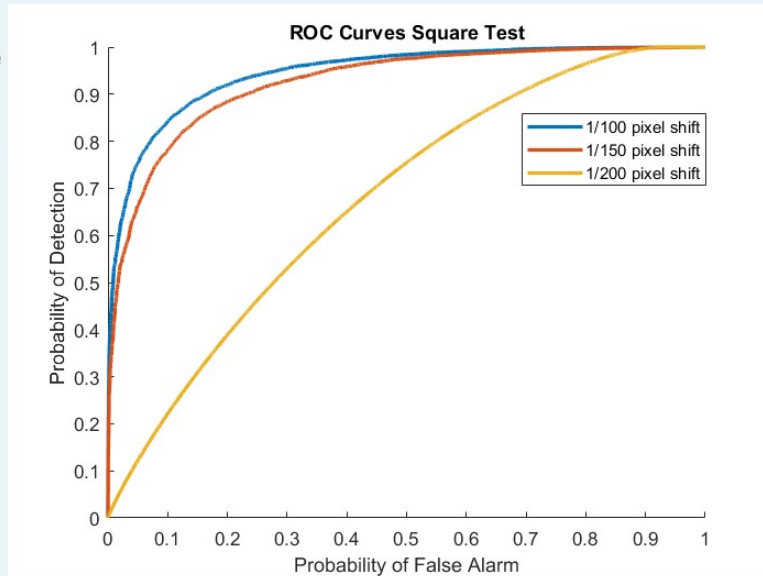
- Squared Difference

Number of Pixels:

- 500

Number of Samples:

- 10,000



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## Conclusion

Conclusions:

- Built an oscillating rod and measured it in a controlled low vibration environment with a RED video camera.
- Used a bank of match filters and multipass polynomial interpolation to find the moving edge of the rod.
- Motion was fit to a harmonic model for all intercepts to bin subpixel shifts
- Achieved subpixel detection down to 1/200 of a pixel.

Future Work:

- Extension of measurements and processing to other video systems.
- Application of processing to detecting building vibrations for upcoming field test.
- Approximate high-resolution video as analog and apply CRLB.

Acknowledgements:

- Mr. Goldman and the ARL Acoustics Branch
- ARL, ASEE, & CQL



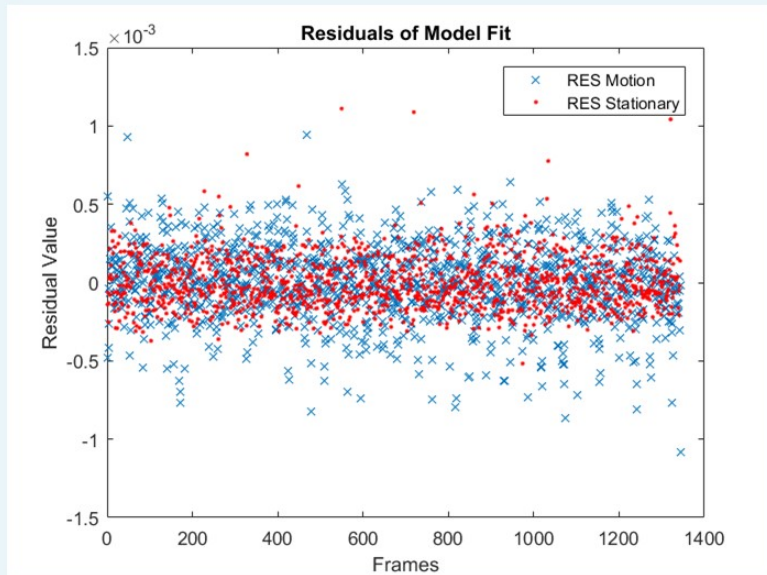
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## Residuals for Slope Fit



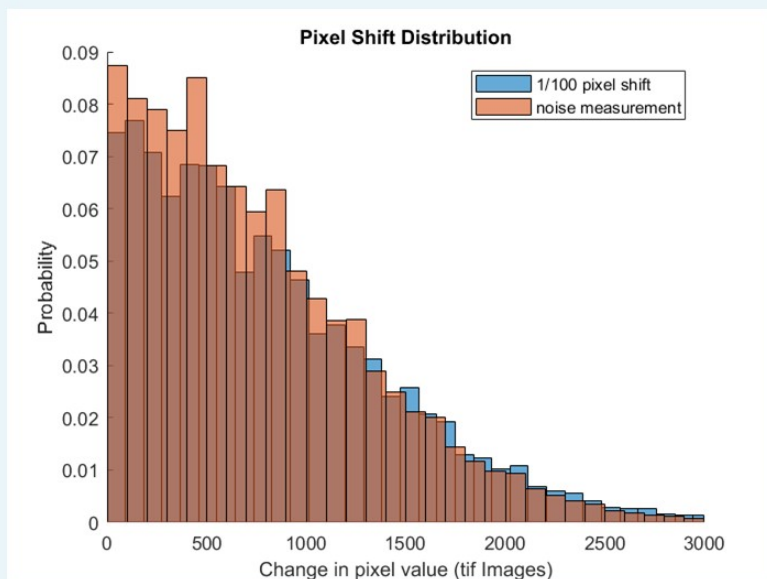
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## Distribution of Pixel Shifts

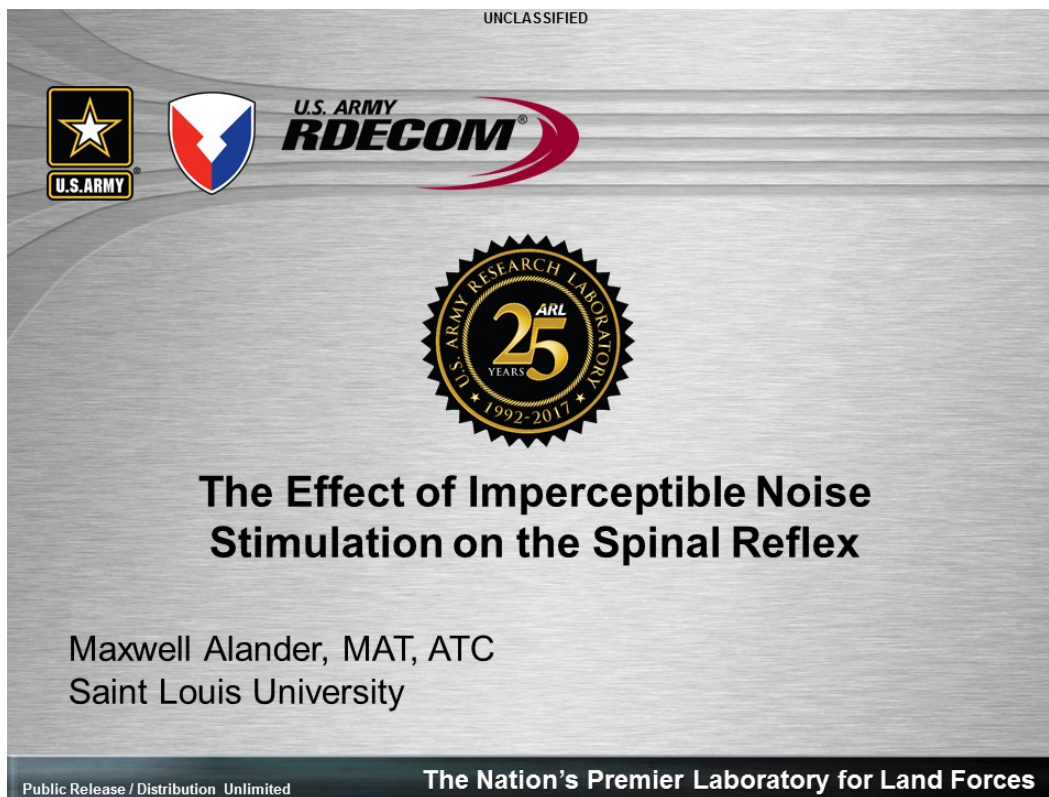


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## Maxwell WH Alander

Maxwell WH Alander made the trip from Missouri to Maryland this summer after graduating with his Master of Athletic Training degree from Saint Louis University. The previous year, he received his BS in Exercise Science from the same institution. Originally a mechanical engineering major, his passion for physiology and performance led him to change his focus. Throughout college, he participated in Division I athletics, Greek life, and served as an assistant to strength and conditioning coaches in the athletics department. When he is not analyzing H-reflex recruitment curves, he can be found paddle boarding in the bay or biking in Susquehanna State Park. His future plans are to explore opportunities in research and sport performance that would allow him to continue contributing to the scientific community.







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**Problem**



- Soldiers require fine motor control for various tasks.
  - Marksmanship
- Tremor can result in a decrease in fine motor control.
  - Deviation from intended or ideal movement
  - Stress and physical exertion  
(Puschmann et al, 2011)

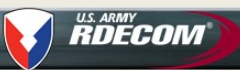



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**Introduction**



- Vibratory noise stimulation has elicited performance increases relevant to Soldiers
  - Works by enhancing sensitivity of sensory input, which in turn affects motor output
- Imperceptible vibratory noise
  - Decrease tremor (Kouzaki et al, 2012)
  - Increase agility (Miranda, 2016)
  - Improve sensorimotor performance (Mendez-Balbuena et al, 2012)
  - Enhance postural stability (Ross et al, 2007)

3

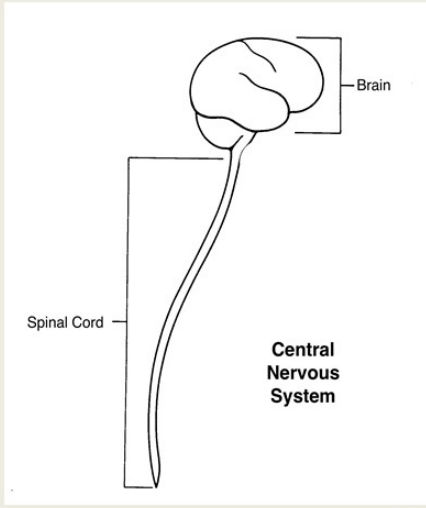
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## Background

- Movement is the product of the integration of motor centers with sensory information.
- Many moving parts
- The aim of this project is to explore motor adaptation to imperceptible noise in the form of vibration on the spinal reflex.
- Attempt to understand short term adaptation to the motor system



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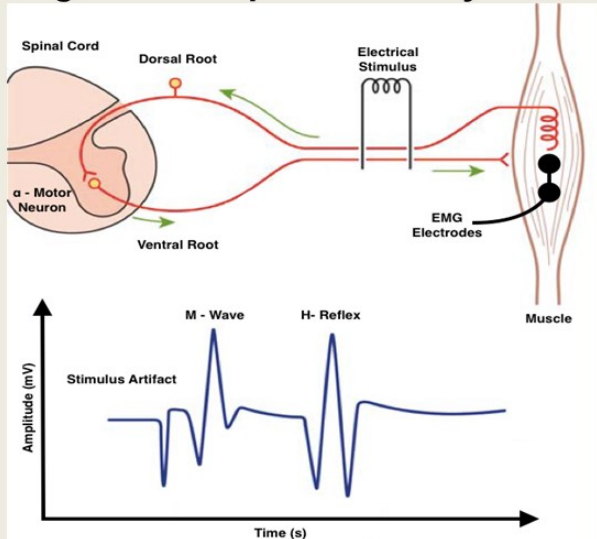
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## Background

### How do we measure changes in the spinal reflex system?

- Tendon tap (myotatic) reflex
- Hoffman reflex



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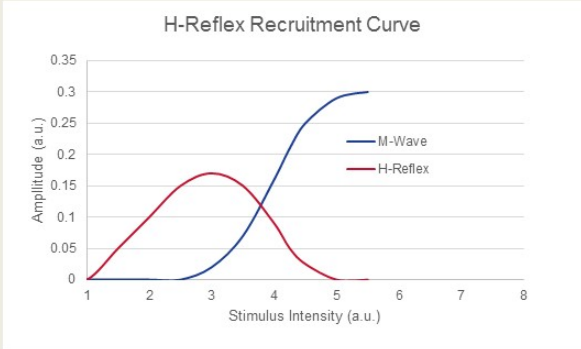
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Background

ARL 25

- H – reflex recruitment curves are used to account for variability between participants.
  - Series of stimulations with increasing intensities
  - Give insight into how an individuals unperturbed spinal reflexes operate



The graph, titled 'H-Reflex Recruitment Curve', plots Amplitude (a.u.) on the y-axis (0 to 0.35) against Stimulus Intensity (a.u.) on the x-axis (1 to 8). The M-Wave (blue line) starts at intensity 3 and rises to a plateau of approximately 0.30 at intensity 5. The H-Reflex (red line) starts at intensity 1, peaks at approximately 0.17 at intensity 3, and then declines to zero by intensity 5.

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My Question

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## How does imperceptible vibratory noise affect the spinal reflex?

**Hypothesis:**

**Vibratory noise stimulus will decrease the spinal reflex**

(Armstrong et al, 2008)



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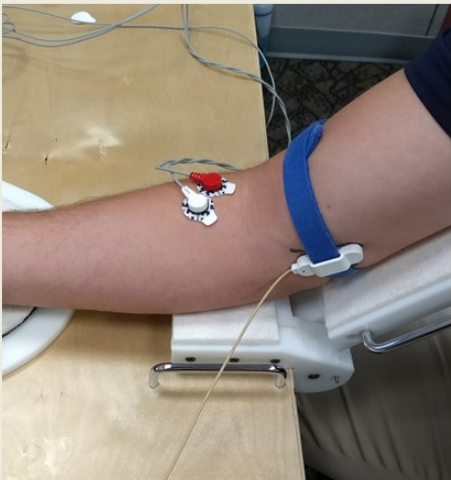
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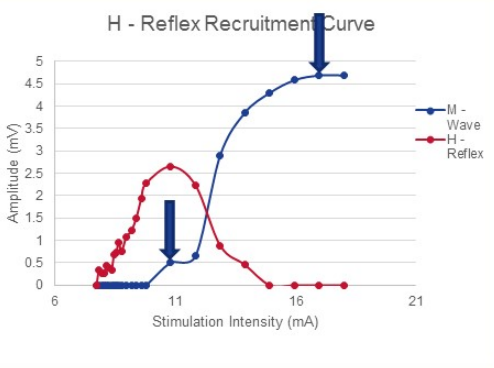
## Methods and Analysis





- A recruitment curve was collected for each of our 12 male participants





**H - Reflex Recruitment Curve**



- Onset of M-wave
  - Standardize stimulation level
- Maximal M-wave
  - Maximum number of MUs that can be recruited

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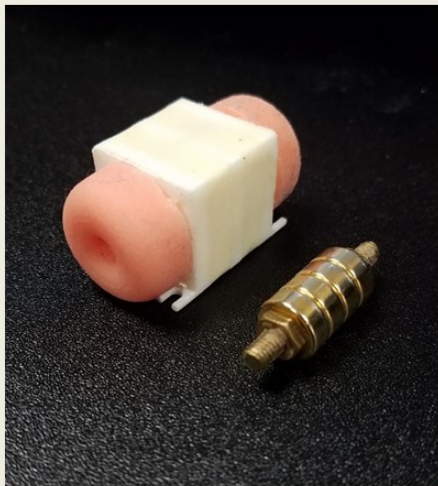
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## Methods and Analysis





- The H – reflex was then gathered under either a randomized vibratory stimulus condition or sham.
  - Stimulated 10 times in one minute
- H-reflex amplitude under both conditions was then normalized to the maximal M-wave for each subject.



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Methods and Analysis







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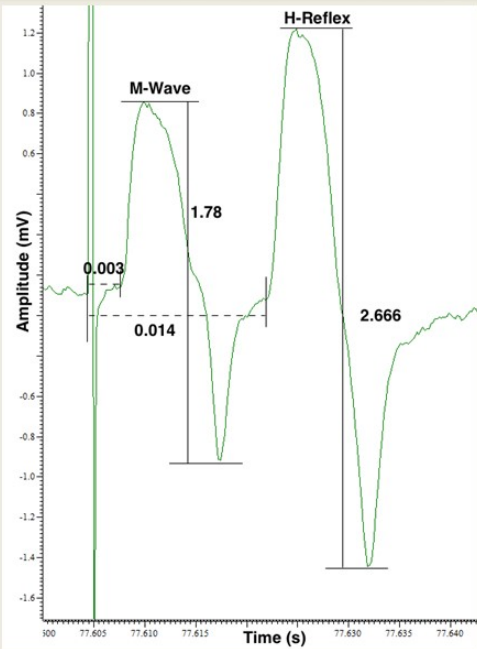



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Methods and Analysis





- Stimulus artifact
- M-wave
- H-wave
- Latency
- Amplitude





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## Results

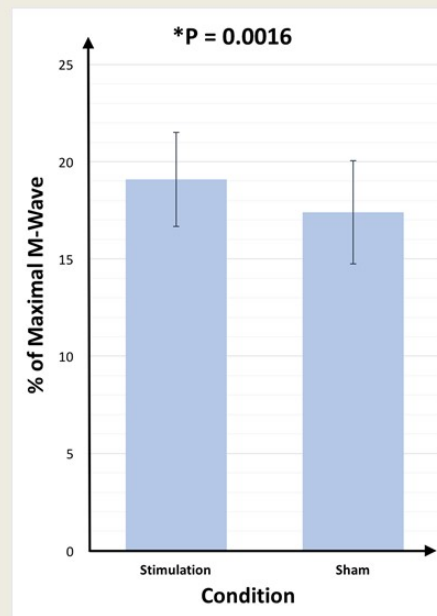



- Generalized linear model
  - Accounts for multiple observations on each subject
- Hypothesis testing performed via Chi square test
  - Does not make assumptions about the distribution of underlying data
- Imperceptible vibration stimulation produced a 1.73% increase in H-reflex amplitude


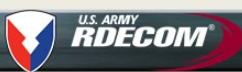
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## Discussion

- The data gathered shows a small but statistically significant increase in the spinal reflex with an imperceptible vibration stimulation.
  - Results did not support my hypothesis
    - Spinal reflex plays a role in motor adaptation induced by vibratory stimuli
- Behavioral outcomes
- Motor level matters
  - Determines...
    - Stimulation time needed to elicit effects
    - Duration of effects

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**RDECOM****Benefits and Future Directions****ARL**

- How can this benefit Soldiers in the field?
  - Potentially increase weapon stability and control
    - Marksmanship task
  - Combat medic
  - Load carriage
  - Other applications
- Next steps
  - Analyzing the effects of noise stimulation on other motor centers
  - Applying noise stimulation to real-world tasks



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**RDECOM****Acknowledgements****ARL**

- I would like to thank Dr. Matthew Tenan and Dr. Courtney Haynes for their guidance, expertise, and mentorship.

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## Citations

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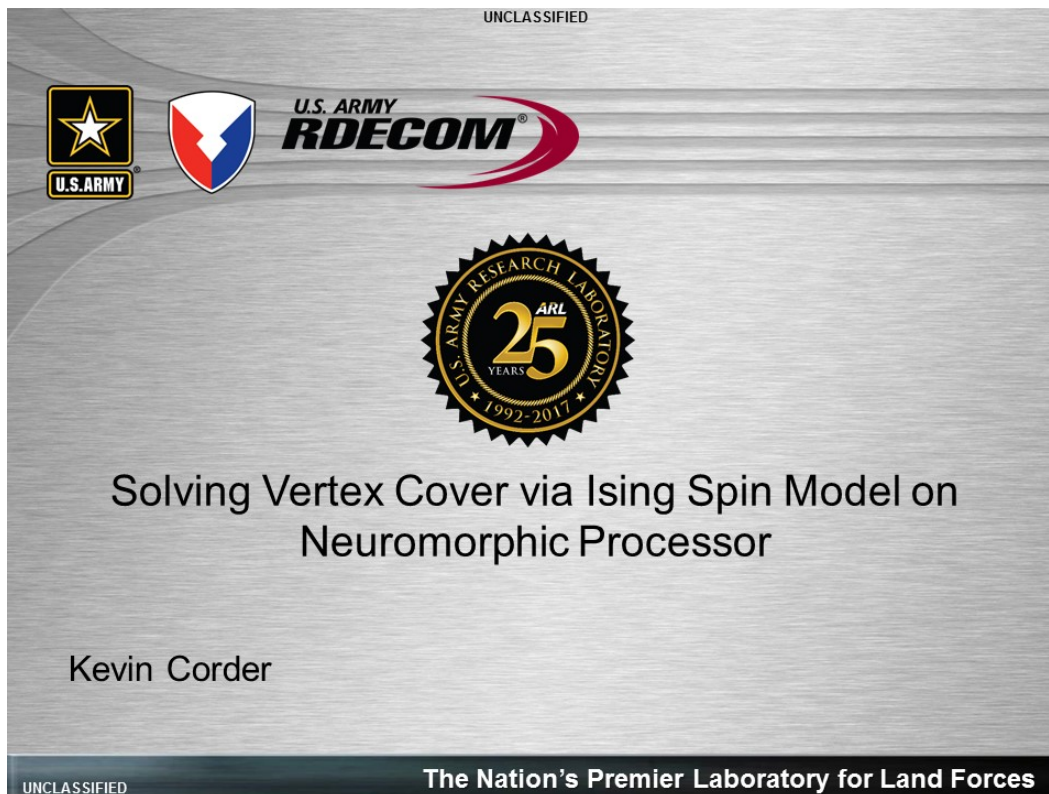
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## Kevin Corder

I am a third-year computer science PhD student at the University of Delaware (UD), where I also received my BS in computer science. I work under Dr Keith Decker in the Multi-Agent Systems Lab at UD, and my research is generally in cooperative multi-agent systems. I have 2 conference papers in review: an approximation method for the Shapley value in feature games, and an improved model for the cooperative information gathering problem.


After this summer project is completed and written up, I plan to continue working with Manny Vindiola at ARL through the remainder of my degree. Through a project in collaboration with Stanford, I will study cooperative deep reinforcement learning and how its neural nets may be implemented on neuromorphic hardware.



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  **About Me**  


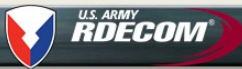


- **Third-year computer science PhD Student**
- **University of Delaware**
- **Studying Multi-agent Systems/Distributed AI with Dr. Keith Decker**
- **This is my 10<sup>th</sup> week at ARL**
- **Mentor: Manny Vindiola**



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  **About the Project**  

- **This project aims to efficiently solve a computationally hard problem—vertex cover—on IBM TrueNorth, a highly distributed and low-power neuromorphic processor.**
- **Vertex cover can represent many real-world problems, like finding the minimal number of gateways in ad hoc or wireless sensor networks where expensive solutions may be infeasible.**
- **To compute vertex cover, we use a distributed Metropolis-Hastings simulation of an Ising model formulation where we converge to a solution by lowering over time the probability of exploration.**

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## NPC on Neuromorphic Chip






- Finding the computational limits of neuromorphic architectures is an open question.
- Our group previously showed TrueNorth to be *Turing complete* (implemented Conway's Game of Life).
- Efficiently solving Minimum Vertex Cover would be proof by example of a neuromorphic processor being able to solve NP-hard problems.
- By NPC reducibility, could potentially solve or provide insights into solving many related hard problems for future neuromorphic architectures.

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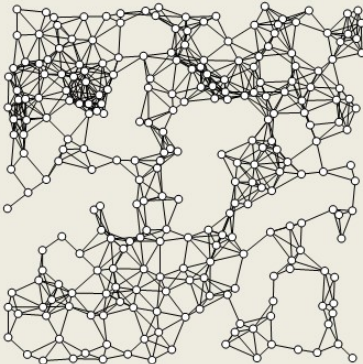



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## Wireless Ad Hoc Networks

- *Ad hoc networks* are dynamic, self-adjusting wireless networks where nodes may move freely
- *Wireless sensor networks*: type of ad hoc network where many small sensors send data to a base station
  - Typically multi-hop to minimize communication energy, where energy efficiency is a major challenge
  - Clustering is common in practice, or...
- Possible application in future: finding minimum number of data-forwarding nodes with Vertex Cover problem
  - Nodes have an edge between them if they are within wireless range
  - All nodes assumed equally good candidates for forwarding data
  - Data forwarding is proactive/hybrid





[https://en.wikipedia.org/wiki/Wireless\\_ad\\_hoc\\_network](https://en.wikipedia.org/wiki/Wireless_ad_hoc_network)

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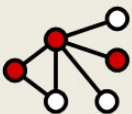

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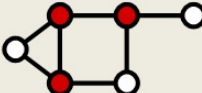
## Vertex Cover



- Given an undirected graph  $G = (V, E)$ , the **Vertex Cover problem (VC)** consists of finding a set of vertices  $V'$  such that every edge has at least one endpoint in  $V'$ 
  - $V'$  is said to **cover** the graph  $G$

- The **minimum Vertex Cover problem (MVC)** is finding a vertex cover  $V'$  with the least possible number of nodes
  - There are  $\geq 1$  minimum vertex covers for any graph  $G$


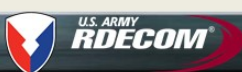



[https://en.wikipedia.org/wiki/Vertex\\_cover](https://en.wikipedia.org/wiki/Vertex_cover)


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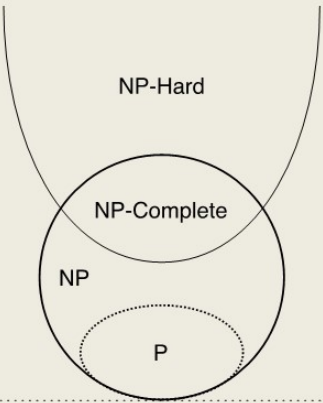
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## Vertex Cover is NP-hard



- However, computing MVC is very difficult for traditional computers.
- NP problems** can be computed by a *nondeterministic* Turing machine in *polynomial time*.
  - Can be *verified* in polynomial time by computer
- NP-hard** problems are not solvable in less than exponential time (... unless  $P=NP$ ).
- NP-complete (NPC)** problems are in both NP and NP-hard.
  - Every problem in NP is reducible to any in NPC, so every NPC problem is reducible to every other.
- Vertex Cover Problem is NP-complete;**  
**Minimum Vertex Cover Problem is NP-hard.**
  - Our implementation could solve other NPC problems reduced to Vertex Cover.
- Vertex Cover may be efficiently computable on a neuromorphic architecture.**



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<https://en.wikipedia.org/wiki/NP-completeness>

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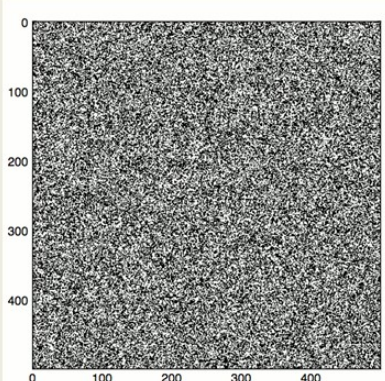


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## Ising Spin Model

- Several NPC problems have been mapped to the *Ising Spin Model*, a model for ferromagnetism from statistical mechanics.
- It models the magnetic dipole moments of atomic integer-spins (+1 or -1) and is used to identify phase transitions.
- Each particle has a spin ( $\sigma_i$ ) and interacts with its neighbors.
  - E.g., 4 neighbors in a 2D grid
  - Local updates lead to global change
- The energy of the spin configuration is given by the Hamiltonian
 
$$H(\sigma) = - \sum_{i,j} J_{i,j} \sigma_i \sigma_j - \mu \sum_j h_j \sigma_j$$

for spin interaction  $J_{i,j}$ , magnetic moment  $\mu$ , and external field  $h_j$
- Spin-site configuration probability from the Boltzmann distribution with inverse temperature  $\beta = (k_B T)^{-1} \geq 0$ :
 
$$P_\beta(\sigma) = \frac{e^{-\beta H(\sigma)}}{\sum_{\sigma} e^{-\beta H(\sigma)}}$$



[https://en.wikipedia.org/wiki/Ising\\_model](https://en.wikipedia.org/wiki/Ising_model)

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## Ising Spin Model Simulation

- The Ising Model has been simulated on CPU/GPU in 2D with the *Metropolis-Hastings* Monte Carlo algorithm using the configuration probability for *Boltzmann exploration*.
- The simulation stochastically reduces the system's energy over time with Boltzmann exploration of a simplified Hamiltonian:
 
$$H(\sigma) = - \sum_{i,j} \sigma_i \sigma_j$$
- The Metropolis-Hastings Ising Model simulation can be summarized as:
  1. Choose a spin site  $k$  with probability  $\frac{1}{N}$  (for  $N$  spin sites)
  2. Compare its local energy contribution to the energy if  $\sigma_k$  were flipped
  3. If new energy is less, keep flipped state
  4. If new energy is more, keep new state with probability  $e^{-\beta(H_v - H_\mu)}$
  5. Repeat

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## Ising Model Metropolis Simulation

- This simulation is slow when run sequentially, so it has also been adapted for GPU implementations [2].
- Since each spin site only depends on its 4 neighbors (in 2D grid), the GPU implementation updates all non-adjacent sites simultaneously.
  - Done with a *checkerboard decomposition* for efficient GPU implementation
  - Decomposition is non-trivial in dimensions  $\geq 2$  and for non-uniform number of neighbors, like graph nodes' degrees

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## Vertex Cover as Ising Model

- The general Ising spin model is NP-complete [3] and a 2014 paper provides mappings of many NP problems to Ising model formulations [1]
  - Vertex Cover is among the few mappings without a complete graph
- State of node  $v$  is  $x_v \in \{0, 1\}$  (1 if contained in vertex cover  $V'$ , or particle has +1 spin), and the system Hamiltonian is  $H = H_A + H_B$ 
  - Constraint that every edge has at least one colored endpoint is
 
$$H_A = A \sum_{u,v \in E} (1 - x_u)(1 - x_v)$$
  - Also want to minimize the number of colored vertices with
 
$$H_B = B \sum_v x_v$$
  - Require that  $B < A$  so total energy is never lowered by uncoloring a vertex that ruins the solution

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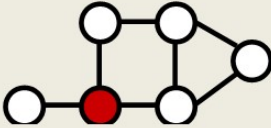



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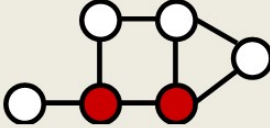
**Vertex Cover as Ising Model**

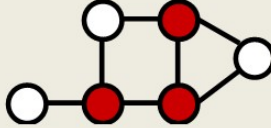
- State of node  $v$  is  $x_v \in \{0, 1\}$ , system Hamiltonian is  $H = H_A + H_B$ , and  $B < A$ 
  - Every edge has at least one colored endpoint:
$$H_A = A \sum_{u,v \in E} (1 - x_u)(1 - x_v)$$
  - Minimize the number of colored vertices with
$$H_B = B \sum_v x_v$$
- Example with  $A = 4, B = 1$ :



$$\begin{aligned} H_A &= 4A \\ H_B &= 1B \\ H &= 17 \end{aligned}$$



$$\begin{aligned} H_A &= 2A \\ H_B &= 2B \\ H &= 10 \end{aligned}$$





$$\begin{aligned} H_A &= 0 \\ H_B &= 3B \\ H &= 3 \end{aligned}$$

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**Vertex Cover as Ising Model**

- The vertex cover Hamiltonian can be rewritten for local energy contribution for each vertex  $v_i$ :
$$\begin{aligned} H &= B \sum_v x_v + A \sum_{u,v \in E} (1 - x_u)(1 - x_v) \\ &= \sum_i^V \left[ Bx_i + \underbrace{\frac{A}{2}(x_i - 1) \cdot \sum_{u:(i,u) \in E} (x_u - 1)}_{H_{local}} \right] \end{aligned}$$
- Just as the other Metropolis-Hastings simulations, we'll lower the temperature over time to converge to a solution.
  - Lower environment temperature  $\rightarrow$  lower exploration probability
  - The speed of lowering temperature is a hyperparameter: we'll need to find speeds that result in global optima for different graph sizes.

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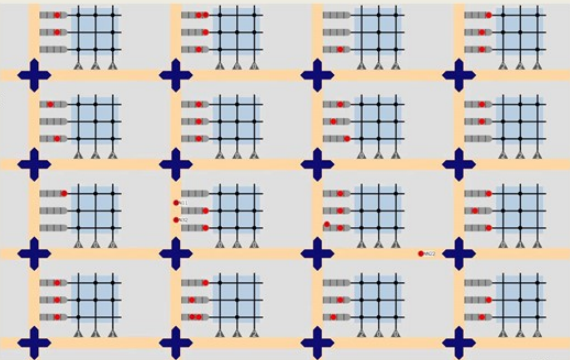
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## IBM TrueNorth

- TrueNorth: “Brain-inspired chip” boasting very low power and massively distributed model of computation
- 4096 cores, each with 256 neurons and 256 axons arranged in crossbar
- Neurons *spike* if the *potential*, the weighted sum of synapses plus leak, exceeds the threshold  $\alpha$  and send to only one axon
- All parameters fixed during execution
- Orders of magnitude slower than traditional CPUs, but parallelism can compensate
- First generation of this chip, as neuromorphic computing is young—could be significant in the future



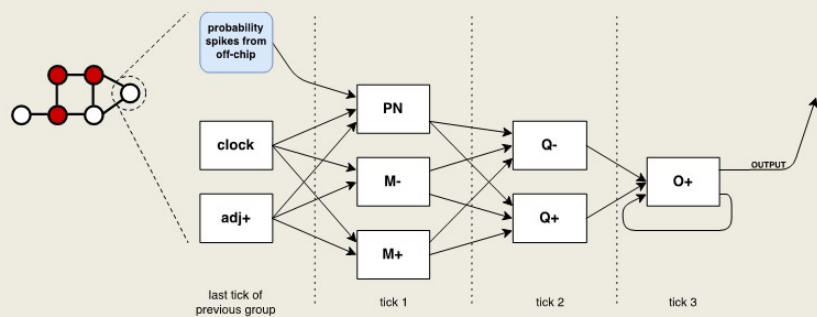
IBM's YouTube: <https://www.youtube.com/watch?v=5izS3IAZHml>

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## TrueNorth Implementation

Each node  $v \in V$  becomes a *node circuit* in the TrueNorth implementation of the Ising model formulation, each connected to other node circuits



But before mapping nodes/connections, we must first determine:

1. Which nodes should go together on cores (and how to set inter-core edges)
2. Which nodes can be updated simultaneously (groups of non-adjacent nodes, similar to “checkerboard decomposition”)

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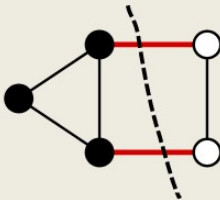


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## Implementation Setup

### 1. Which nodes should go together on cores?

- Connected nodes must send/receive spikes to each others' circuits.
- Since a neuron can only send to 1 axon on 1 core, where all neurons on that core can read its spikes, more intercore edges wastes space.
  - Want the *most connected subgraphs* to share the same core
- This becomes a **graph partitioning problem** to find the *minimum cut* of the graph (find least number of edges to bisect graph).
  - Another NP-hard problem!
  - We use spectral bisection, a greedy solution, for time efficiency at the expense of non-optimal space.
- Bisected graph may not fit on a core, so we *recursively partition each subgraph* until it does.



A minimum cut.  
[https://en.wikipedia.org/wiki/Cut\\_\(graph\\_theory\)](https://en.wikipedia.org/wiki/Cut_(graph_theory))

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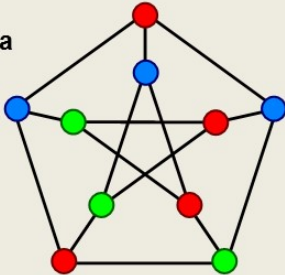
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## Implementation Setup

### 2. Which nodes can be updated simultaneously?

- Need groups of non-adjacent nodes, like the “checkerboard decomposition” for the 2D Ising model simulation.
- Each node  $v$  may update concurrently with each non-adjacent node  $u \in V : (u, v) \notin E$ .
- This is a **graph coloring problem**: find the minimum number of colors needed to assign every node  $v \in V$  a color such that no 2 adjacent nodes have the same color.
  - Also NP-hard! Again, we use a greedy solution.
- The nodes assigned the same color becomes a **group** of nodes that may be updated simultaneously.
- Nodes' circuits will be activated by a group **clock neuron** according to their graph coloring result.

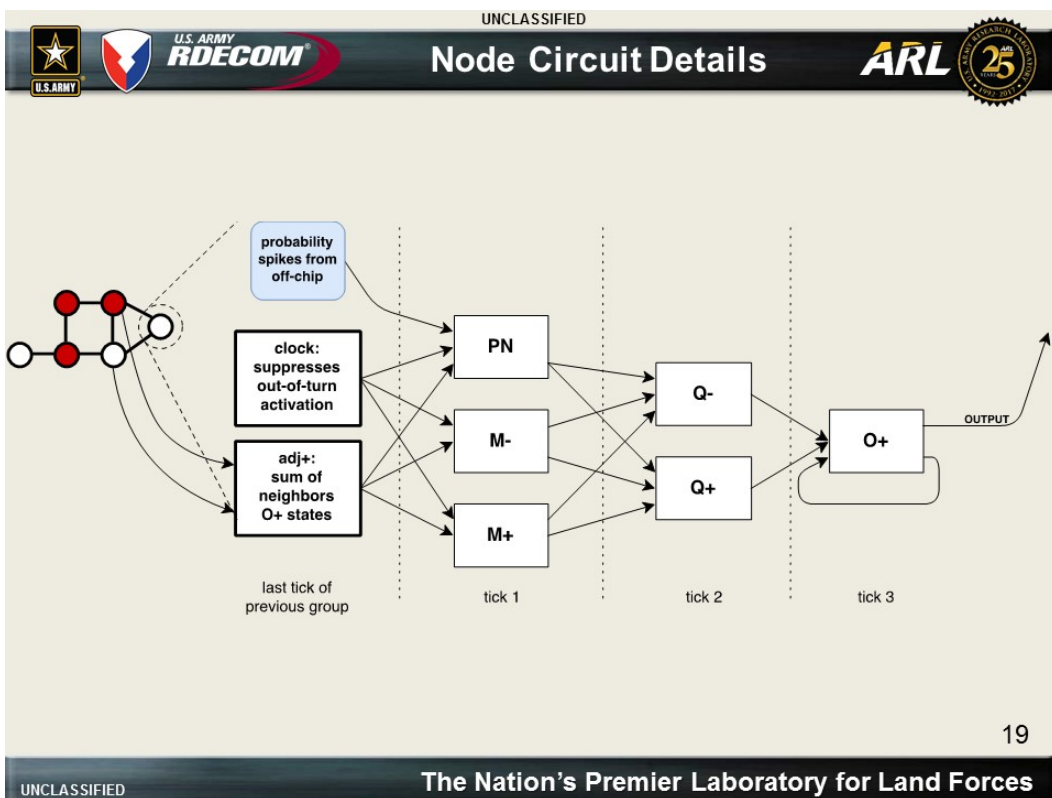
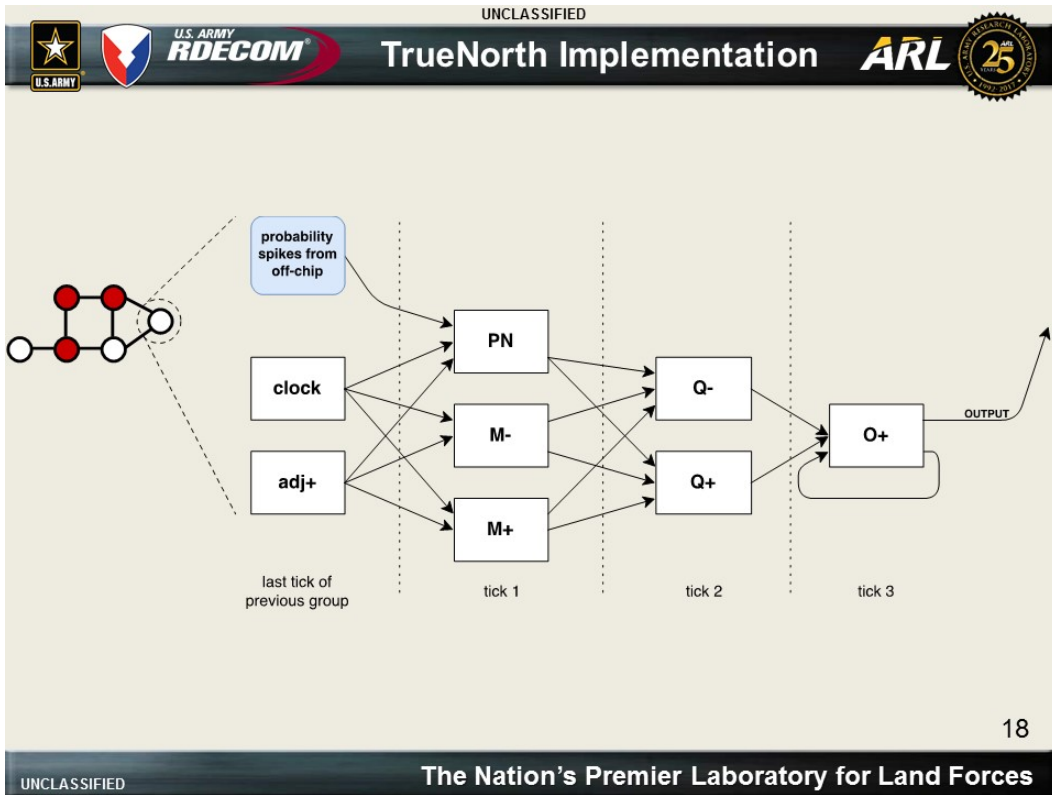


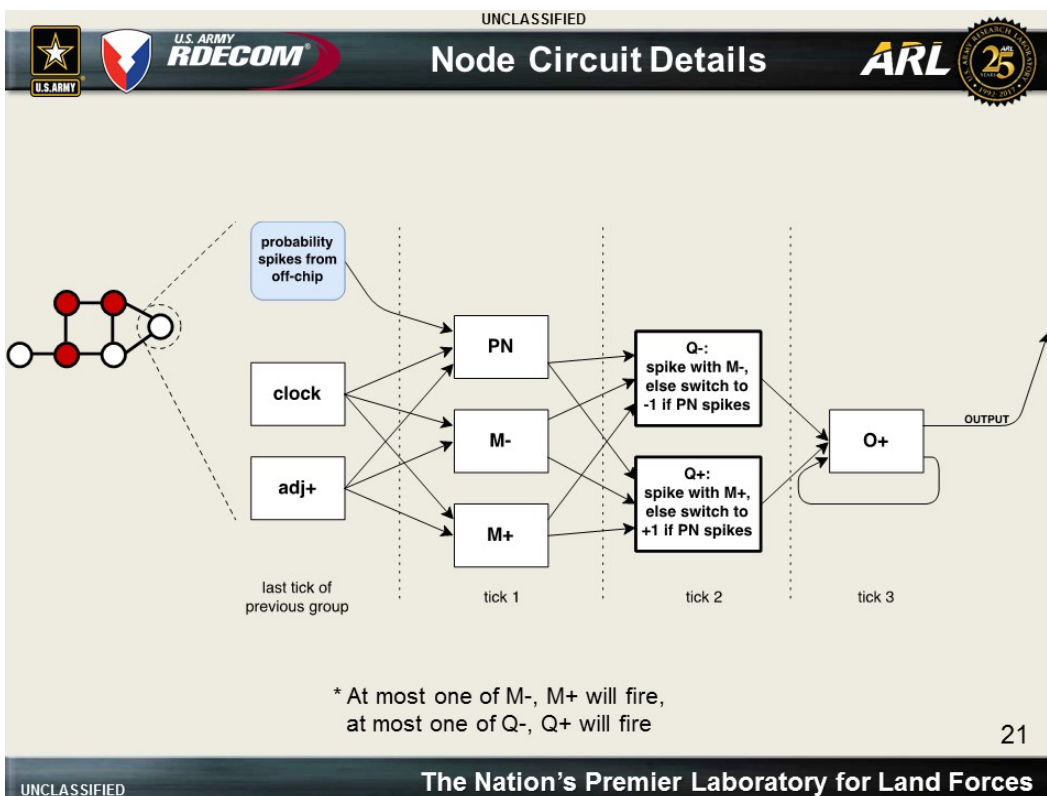
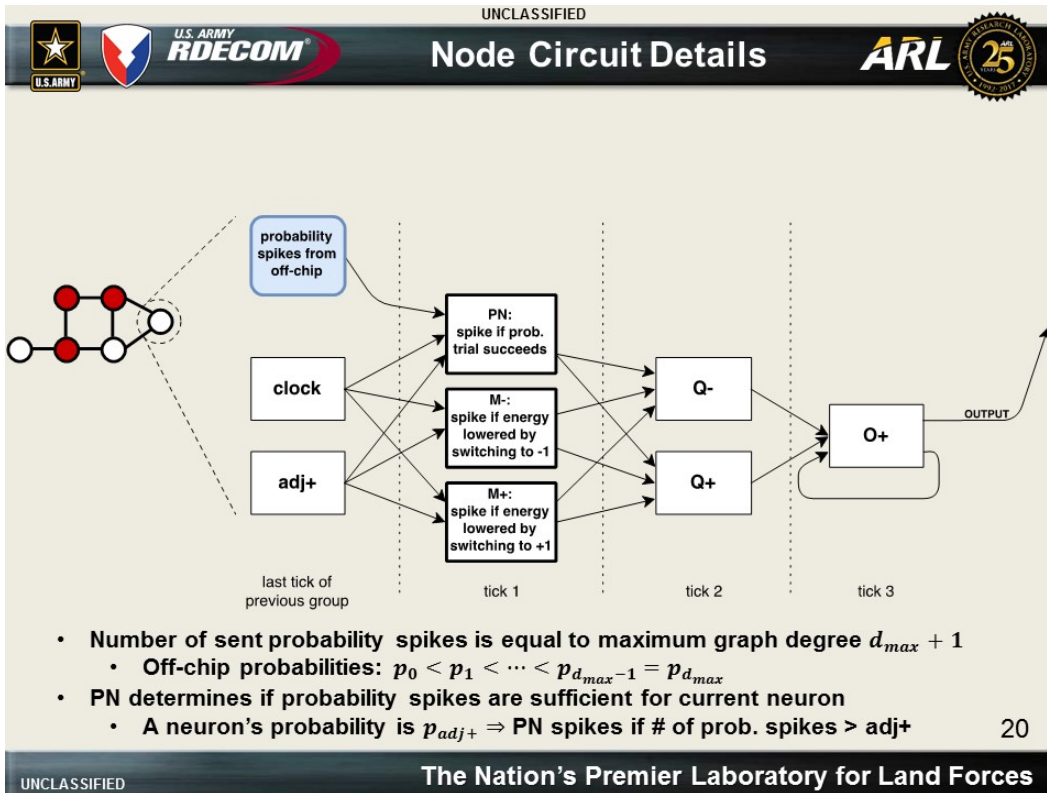
[https://en.wikipedia.org/wiki/Graph\\_coloring](https://en.wikipedia.org/wiki/Graph_coloring)

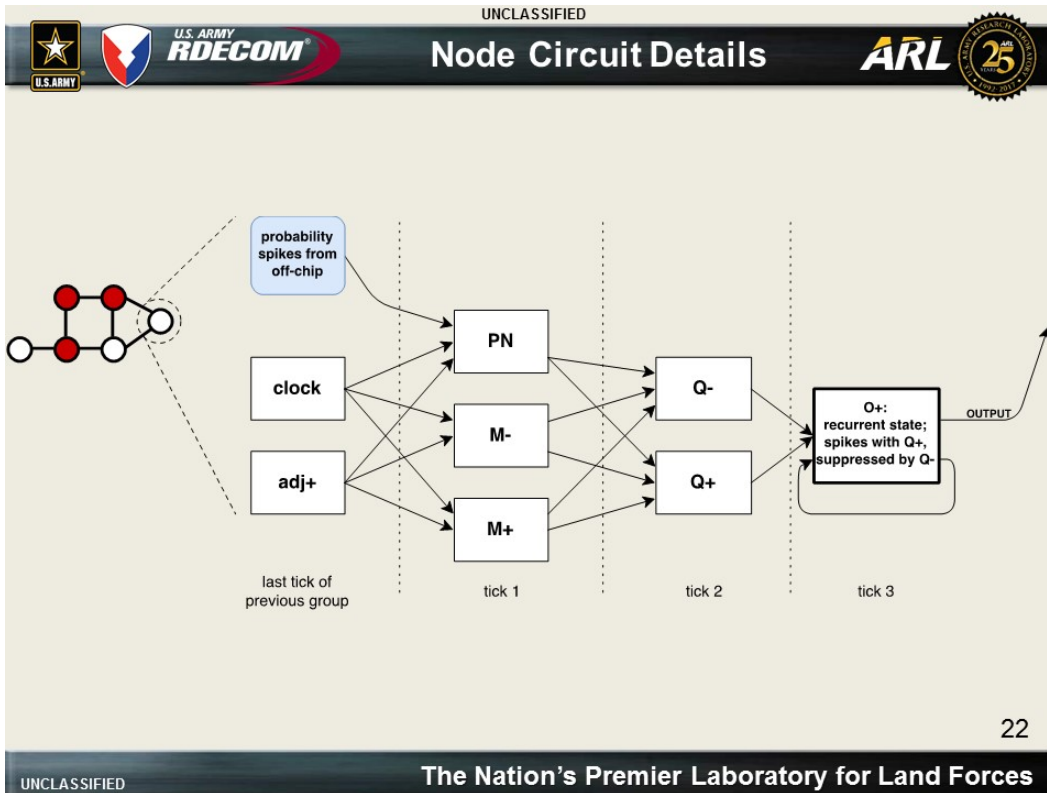
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## Results


- **Implementation is under way!**
    - Currently unit testing components, testing them together after
  - **Timeline in weeks:**
    - 1-2: learned about TrueNorth architecture and corelet programming
    - 3: learned about Ising models and their simulations
    - 4: wrote TrueNorth corelet for 2D Ising simulation until determined feasible
    - 5: Found mappings of NP problems to Ising; chose Vertex Cover
    - 6-9: Designing the TrueNorth Ising simulation for Vertex Cover
    - 10: Started implementing pieces for small graphs
  - **After implemented, we will test the solution quality vs. the speed of lowering environment temperature for various graphs to learn a good boundary dependent on graph degree.**
  - **For various graphs, we will then compare solution quality, runtime, and power consumption of our implementation against:**
    - CPU/GPU Ising simulations solving Vertex Cover
    - Greedy, polynomial solutions
    - Exact solution (exponential-time ground truth)
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## Limitations

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- **Hardware:**
  - Probabilities need to be computed off-chip (can't adjust parameters to affect probability dynamically).
  - Adding/removing graph nodes or edges requires reinitializing because of fixed connection.
  - Graphs with large degree may not fit on the chip to solve at all.
- **Method:**
  - Takes unknown number of iterations of lowering system temperature to converge, and may not find global optima if lowered too quickly (but guaranteed with enough time).
    - Need to learn this hyperparameter with trials

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## Conclusion & Future Work

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- In this project, we've detailed a simulation to solve the NP-hard Vertex Cover problem on a neuromorphic processor, which could have significant impact on future neuromorphic algorithms for solving hard problems.
- This could be used in situations like ad hoc wireless sensor networks on the battlefield, where a minimal number of gateways may need to be computed frequently and with low power.
- To improve this project, could increase efficiency by reusing probability axons between update groups.
- We want to reduce to Vertex Cover a different NPC problem (perhaps Set Cover) and see quality of results for NPC problems, in general.

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- [1] E. E. Ferrero, J. P. De Francesco, N. Wolovick, and S. A. Cannas, "Q-state Potts model metastability study using optimized GPU-based Monte Carlo algorithms," *Comput. Phys. Commun.*, vol. 183, no. 8, pp. 1578–1587, 2012.
- [2] A. Lucas, "Ising formulations of many NP problems," *Frontiers in Physics* 2, 5. pp. 1–15, 2013.
- [3] F. Barahona, "On the computational complexity of Ising spin glass models," *J. Phys. A Math. Gen*, vol. 15, pp. 3241–3253, 1982.

## Questions?

## Matt Mansell

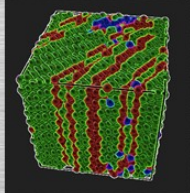
I am originally from Birmingham, Alabama. I obtained my bachelor's degree in chemical engineering and mathematics from Vanderbilt University. For several years, I worked for NASA as a Life Support Systems Development Engineer at the Marshall Space Flight Center in Huntsville, Alabama. I am now a full-time graduate student entering my third year at North Carolina State University (NCSU), where I am advised by Profs Keith Gubbins and Erik Santiso. At NCSU, I use theory and simulations at the quantum and atomistic scale to study fluids in extreme confinement. My future plans are to complete my PhD, and then continue pursuing my passion for molecular simulation and theories of fluids, as well as my passion for teaching and communicating science, either as a professor or at a US government laboratory.

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**Modeling RDX Decomposition Products with  
Mesoscale Particles**  
ARL Internship Presentation 2017

**James (Matt) Mansell**  
Pls: John Brennan, Jim Larentzos (WMRD, EMSB)



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Bio



### Professional

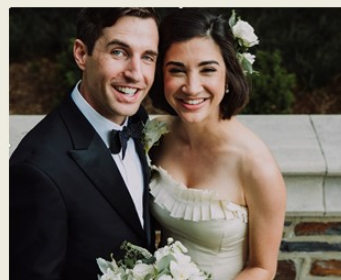
- BE in Chemical Eng and Math (Vanderbilt University)
- NASA Marshall Space Flight Center (Huntsville, AL)
- NC State University, Dept. of Chemical & Biomolecular Engineering
  - Academic advisors: Keith Gubbins, Erik Santiso
  - Topics: Molecular theory of fluids, quantum/DFT/atomistic simulation



**NC STATE UNIVERSITY**

### Personal

- **I got married!** 2017-06-24, Durham, NC



### Future Plans

- Continue working in theory/simulation of fluids and interfaces, ideally in an academic setting or government lab

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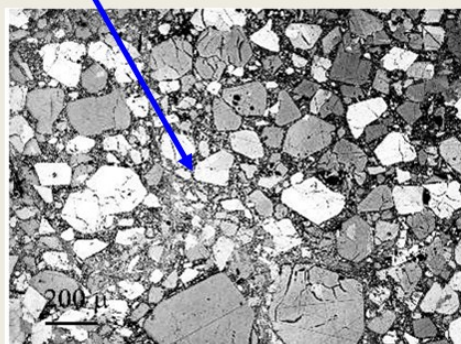
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Energetic Material Structure



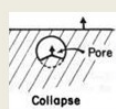
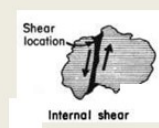
### Microstructure Feature Scales

200.0  $\mu\text{m}$   
2.5  $\mu\text{m}$



Skidmore, C.B., Phillips, D.S., Howe, P.M., Mang, J.T., and Romero, J.A., 1998, 11th International Detonation Symposium, Snowmass Village, Colorado, pp. 556.

### Hot spot mechanisms (ENERGY LOCALIZATION)



- ❑ EM composites are highly microstructured
- ❑ Sensitivity and performance believed to be due to "hot spots"

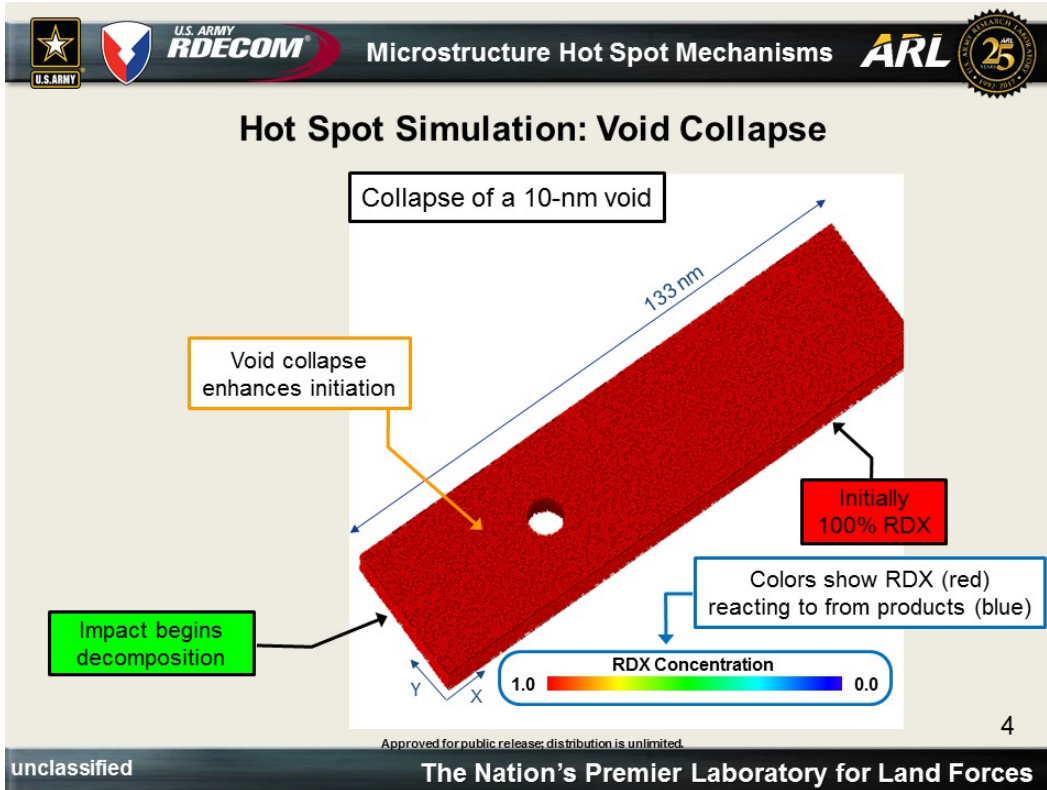
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### Representing Every Atom Explicitly is Not Feasible

Initial # RDX Molecules	# of Processor Cores	Explicit Atom Simulation Time (Estimated)	DPD Simulation Time
20,452,820	10,368	7.3 years	3.75 hours
126,259,367	63,232	7.4 years	4.34 hours
1,126,926,339	564,480	7.4 years	5.59 hours


Simulations used the same time step size and total time.

\*Simulations ran on the Trinity KNL (Phase 2) supercomputer, located at Los Alamos National Laboratory

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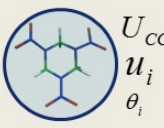
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## Coarse-Graining of Chemical Reactions



**ARL**

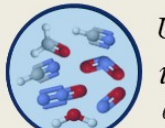
### RDX Decomposition



$U_{CG}$   
 $u_i$   
 $\theta_i$

RDX

decomposition



$U'_{CG}$   
 $u'_i$   
 $\theta'_i$

Product Gas Mixture  
(HCN, NO<sub>2</sub>, NO, H<sub>2</sub>O, N<sub>2</sub>, H<sub>2</sub>, CO, CO<sub>2</sub>)

#### Reduced Reaction Model

<chem>RDX -&gt; 3HCN + 3/2(NO2 + NO + H2O)</chem>	endothermic
<chem>HCN + NO2 -&gt; NO + 1/2(N2 + H2) + CO</chem>	exothermic
<chem>HCN + NO -&gt; CO + N2 + 1/2H2</chem>	
<chem>NO + CO -&gt; 1/2N2 + CO2</chem>	

\*Kinetic model reduction performed by Igor Schweigert at NRL

**\*Arrhenius Form**

$$k_{Rx}(\theta_i) = A_{Rx} e^{-E_{a,Rx}/k_B\theta_i}$$

**COARSE-GRAINING OF CHEMICALLY REACTING SYSTEMS:**

✓ BIG CHALLENGES


✓ BIG POTENTIAL REWARDS

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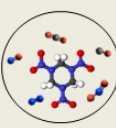
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## Method: DPD-RX

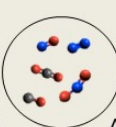


**ARL**

### Dissipative Particle Dynamics with Reactions (DPD-RX)




RDX




Product Gas (PG)

1-Fluid Approximation



1-Fluid Molecule  
(Hypothetical)

Equation of State



Composite DPD particle

Internal State

Density

Temperature

Composition

"Many-Body Force-Field" (MBDPD)

Interparticle Forces

Conservative

Stochastic

Frictional

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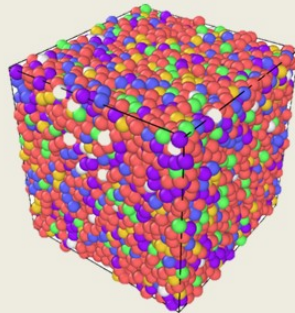
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## Motivation

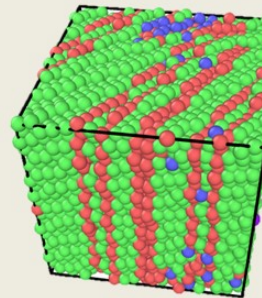
- Deficiencies of the current Product Gas Model (PGM):
  - crystallization/ordering PG structure

1-Fluid Simulation:  
1.8 g/cc, 3445 K  
 $N_{pg} = 8.684$ .



Unstructured

1-Fluid Simulation:  
1.8 g/cc, 2836 K  
 $N_{pg} = 7.721$ .



Structured

● HCP  
● Simple Cubic  
● FCC  
● ICO  
● BCC  
○ Other

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## Motivation

- Deficiencies of the current Product Gas Model (PGM):
  - crystallization/ordering PG structure
  - thermodynamic properties off by 20-50% or more
  - ad-hoc scaling

## Hypothesis

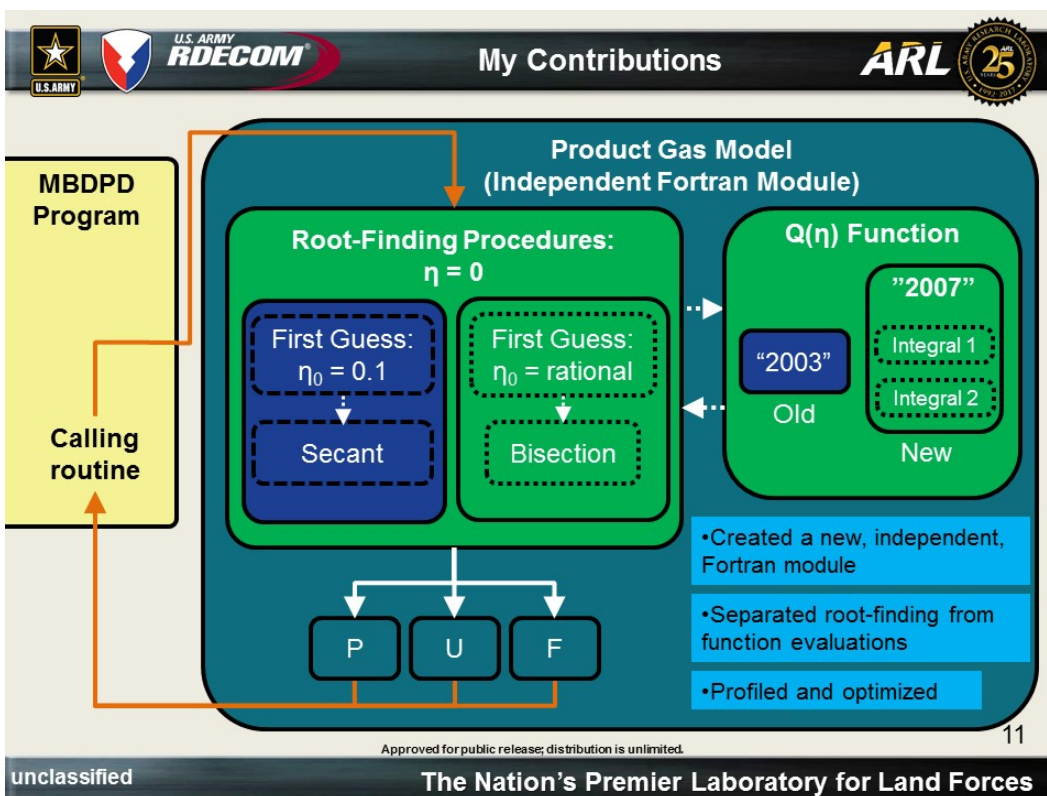
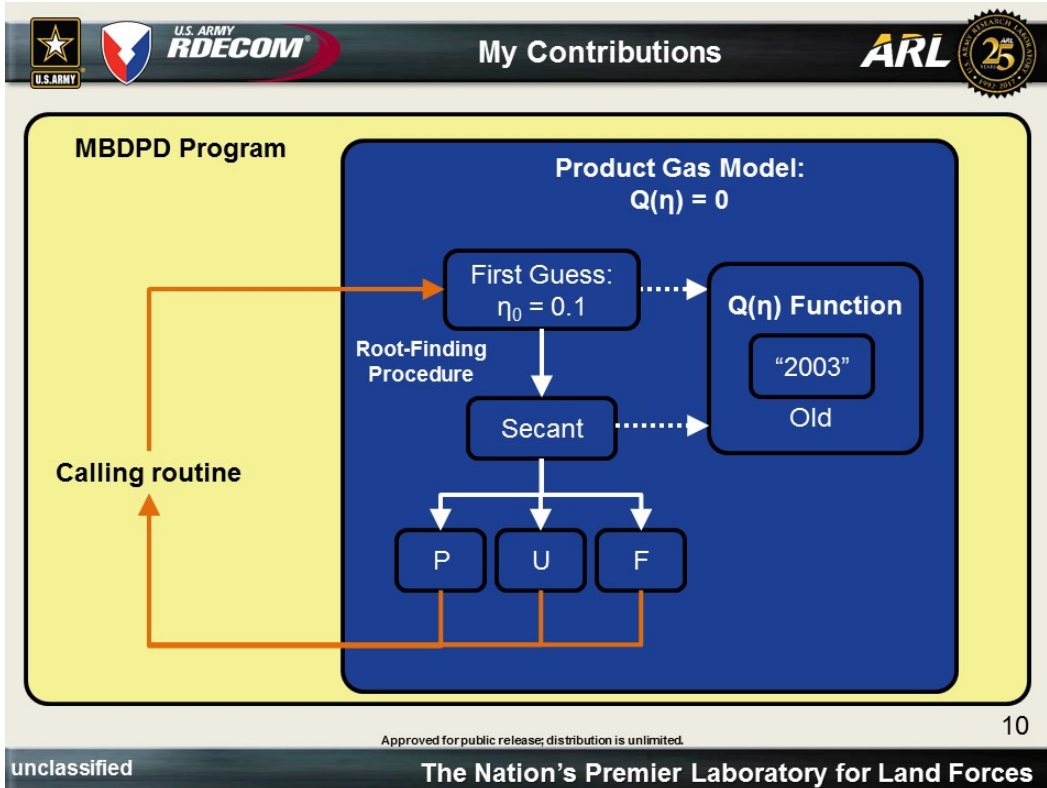
- A new PGM will be more accurate and versatile, and at least as computationally efficient as the current PG Model.

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## The "2007" Equation of State

**Exponential-6 Potential:**

$$\phi(r) = \frac{\epsilon_0}{\alpha - 6} \left[ 6e^{\alpha(1-r/r_e)} - \alpha \left( \frac{r_e}{r} \right)^6 \right] \quad (7)$$

**Equation of State for a Fluid Composed of Exponential-6 Particles**

$$Q(\eta) = \frac{4 - 2\eta}{(1 - \eta)^3} - (1/2 + 2\eta + 2\eta^3) + \frac{\partial}{\partial \eta} \frac{F_1}{NkT} = 0 \quad (16)$$

$$\frac{\partial}{\partial \eta} \frac{F_1}{NkT} = \frac{1}{\eta} \left( \frac{F_1}{NkT} - \frac{PV}{NkT} + 1 \right) - \frac{\eta \beta \epsilon_0}{\alpha - 6} \times \left[ 72e^{\alpha} G''_{\eta}(\alpha \lambda^{-1}) + (\alpha \lambda^6 / 2) \int_0^{\infty} G'_{\eta}(t) t^4 dt \right] \quad (17)$$

$$\frac{F_1}{NkT} = -\frac{\eta \beta \epsilon_0}{\alpha - 6} \left[ 72e^{\alpha} G'_t(\alpha \lambda^{-1}) + (\alpha \lambda^6 / 2) \int_0^{\infty} G(t) t^4 dt \right] \quad (12)$$

$$\frac{PV}{NkT} = 1 + \frac{24\eta \beta \epsilon_0}{\alpha - 6} e^{\alpha} \alpha \lambda^{-1} \cdot G''_{\eta}(\alpha \lambda^{-1}) - \frac{\alpha \eta \beta \epsilon_0}{\alpha - 6} \lambda^6 \int_0^{\infty} G(t) t^4 dt \quad (14)$$

$$\lambda = (r_e/d) = (\eta_e/\eta)^{1/3}, \quad \eta_e = \pi \rho r_e^3 / 6 \quad (8)$$

Sun, J., Wu, Q., Cai, L. & Jing, F. *Chemical Physics Letters* 449, 72–76 (2007).

$$G(t) = \frac{tL(t)}{Q(t)} \quad (A1)$$

$$Q(t) = 12\eta L(t) + S(t)e^t \quad (A2)$$

$$Q'_t(t) = 12\eta L'_t(t) + 12\eta L''_t(t) + S'_t(t)e^t \quad (A3)$$

$$Q''_t(t) = 12\eta L''_t(t) + S'_t(t)e^t + S(t)e^t \quad (A4)$$

$$Q'''_t(t) = 12L'''_t(t) + 12\eta L'''_t(t) + S''_t(t)e^t + S'_t(t)e^t \quad (A5)$$

$$Q''''_t(t) = S'''_t(t)e^t + 2S'_t(t)e^t + S(t)e^t \quad (A6)$$

$$L(t) = (1 + \eta/2)t + (1 + 2\eta) \quad (A7)$$

$$S(t) = (1 - \eta)^2 t^2 + 6\eta(1 - \eta)t^2 + 18\eta^2 t - 12\eta(1 + 2\eta) \quad (A8)$$

$$G'_t(t) = G(t)L^{-1}(t)L'_t(t) - G^2(t)[tL(t)]^{-1}Q'_t(t) \quad (A9)$$

$$G'_t(t) = G(t)[t^{-1} + L^{-1}(t)L'_t(t)] - G^2(t)[tL(t)]^{-1}Q'_t(t) \quad (A10)$$

$$G''_t(t) = G'_t(t)L^{-1}(t)L'_t(t) + G(t)L^{-2}(t)[L(t)L''_t(t) - L'_t(t)L'_t(t)] - G^2(t)[tL(t)]^{-2}[2Q(t)G'_t(t) - L(t) - tL'_t(t)]Q'_t(t) - G^2(t)[tL(t)]^{-1}Q''_t(t) \quad (A11)$$

$$G''_t(t) = G'_t(t)[t^{-1} + L^{-1}(t)L'_t(t)] - G(t)[t^{-2} + L^{-2}(t)L'_t(t)L'_t(t)] - G^2(t)[tL(t)]^{-2}[2Q(t)G'_t(t) - L(t) - tL'_t(t)]Q'_t(t) - G^2(t)[tL(t)]^{-1}Q''_t(t) \quad (A12)$$

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## Methods: Testing the PG Model

Baseline: Explicit-Molecule

1-Fluid (Molecular Dynamics @ constant energy)

- Simulations defined by:
  - Density
  - Temperature
  - Composition

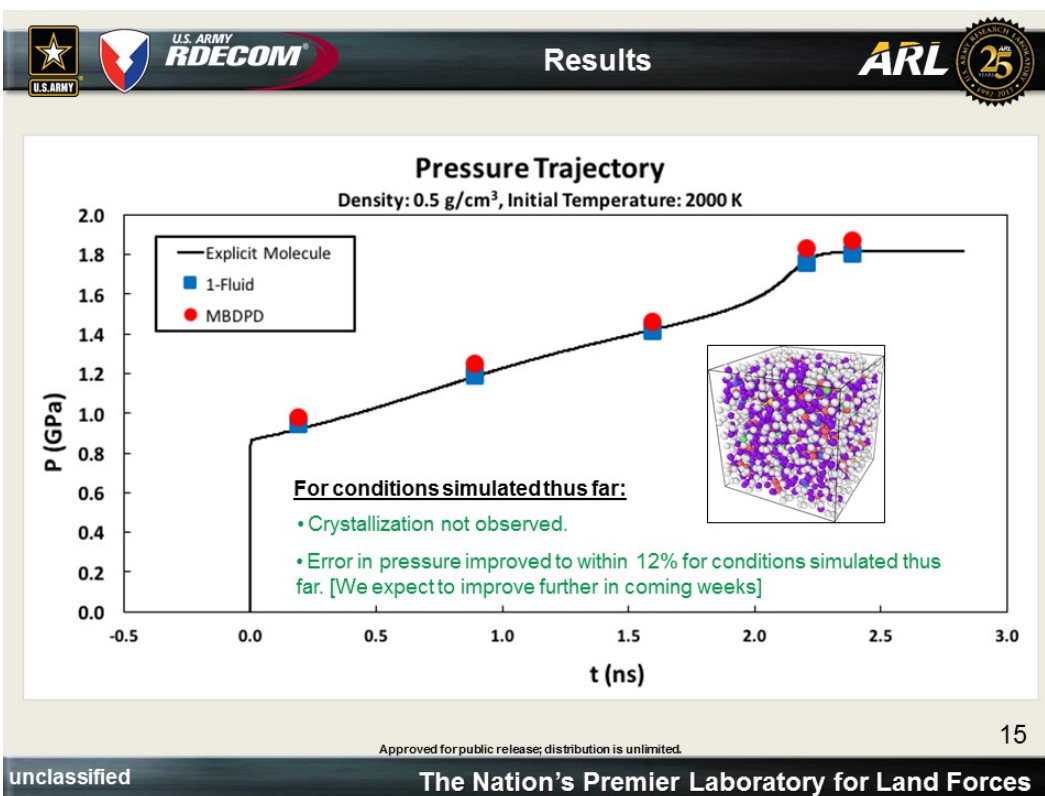
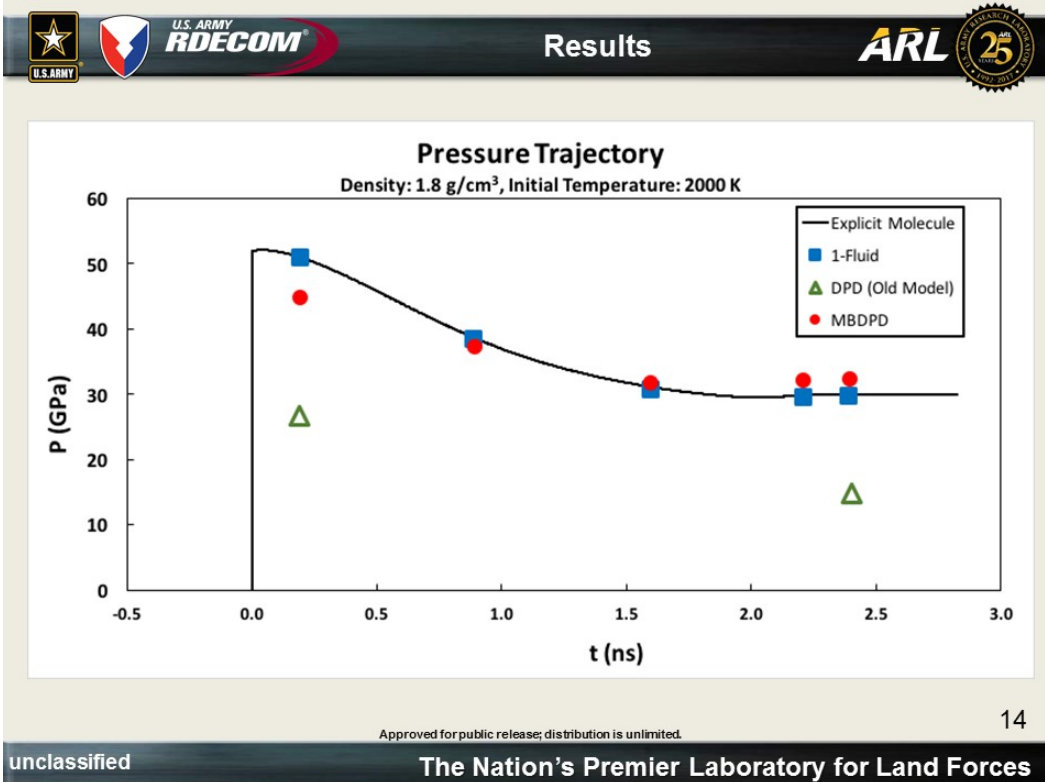
DPD @ constant temperature

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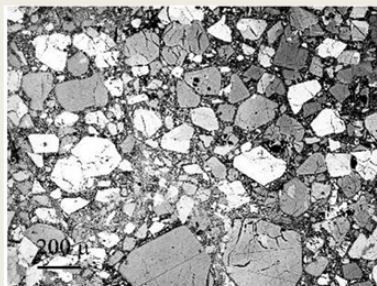
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## Conclusions/Significance

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- **Advancing a very new and promising field: coarse-graining of chemically reacting systems**
- Performance permitted simulations MUCH faster than explicit molecule simulation
- Potential application to other materials
- Better, larger-scale models = improved understanding of microstructure effects = ...
  - Less risk
  - Less cost
  - Higher quality
  - **SAFER SOLDIERS**



Skidmore, C.B., Phillips, D.S., Howe, P.M., Mang, J.T., and Romero, J.A., 11th International Detonation Symposium, Snowmass Village, Colorado, pp. 556.

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## Ongoing Work

- Continue development, debugging, integration, and demonstration of the new PGM
- Computational cost comparisons
- Complete planned table of simulations

## Future Work

- Publication in progress
- Integration into LAMMPS software (widely used particle simulator)
- Integration into/Demonstration of reactive models

## Experience Gained So Far

- |                            |  |
|----------------------------|--|
| • Excalibur/HPC            | • Git                                  |
| • Parallelization (OpenMP) | • Code profiling/optimization          |
| • Batch schedulers (PBS)   | • Dakota                               |
| • Fortran                  | • Engility (Tim Mattox, Mike Lasinski) |
| • Python                   |  |

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## Acknowledgements

**ARL**



- Mentors
  - John Brennan
  - Jim Larentzos
- Mike Fortunato (HIP and Univ. of Florida)
- HPC Modernization Program (HPCMP)
- HPC Internship Program (HIP)
- HPCMP PETTT Initiative
- Rebecca

## Questions?

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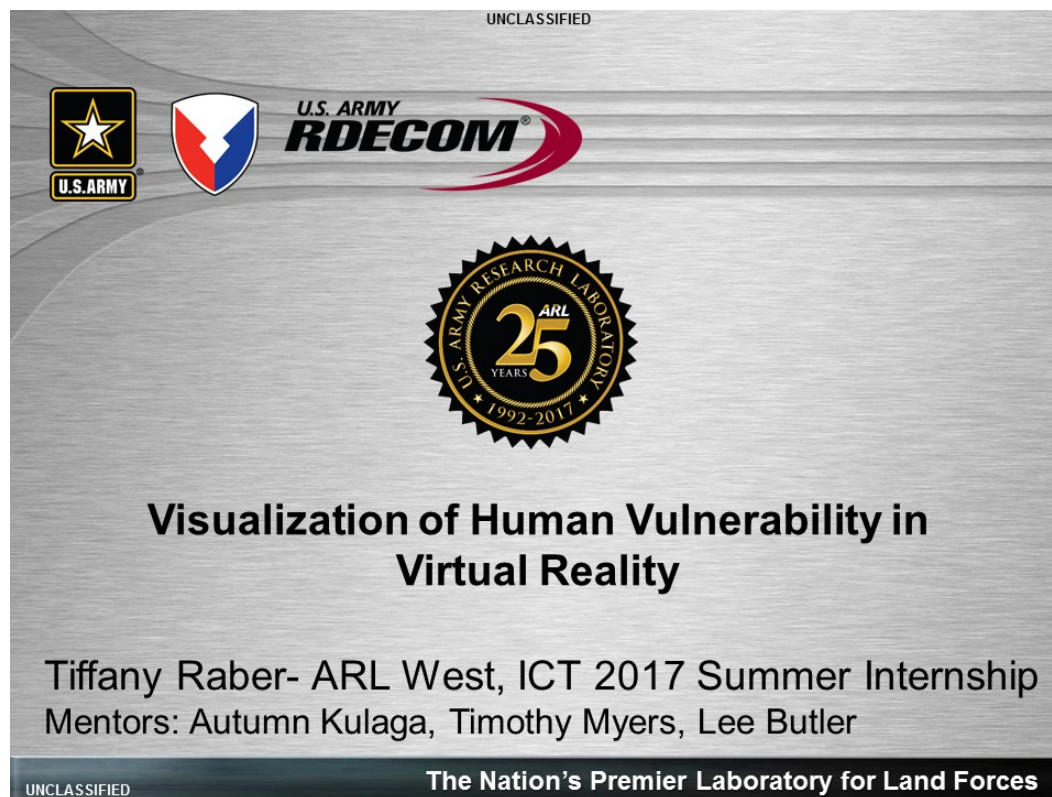
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## Tiffany Raber


Tiffany Raber is a graduate of the Biomedical Visualization Graduate Program (BVIS) at the University of Illinois at Chicago, having received her master's degree in 2017. As a student, Tiffany grew interested in interactive medical education/simulation techniques, with a specific focus in Unity development and 3D asset creation in the AR/VR space. She believes that the advancement of MedVR will directly impact the field, improving patient experience, surgical training, science education, and user health. Currently, Tiffany is a Visiting Research Assistant, working in modeling and simulation in VR, at The US Army Research Laboratory West, located at the University of Southern California's Institute for Creative Technologies.

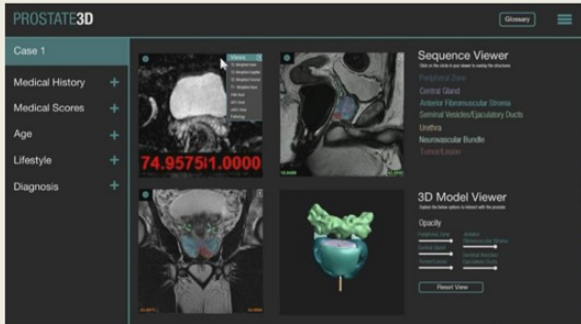



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# About Me










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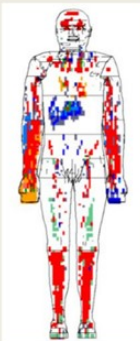
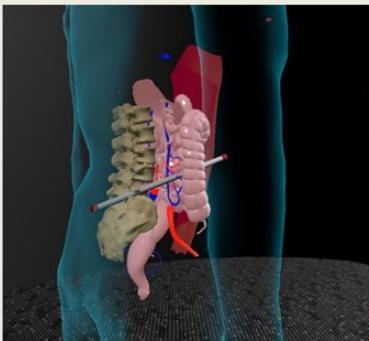



# Background



## Project Description

This research explored methods for displaying Operational Requirements Casualty-based Assessment (ORCA) model output in an immersive and interactive environment. We used virtual reality (VR) to explore the use case of a multimodal analysis tool to help understand shot trajectory tracing, output of injury code, and tissue type/name for DoD analyst evaluation of human system-level survivability and lethality studies.

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# Background

## ORCA Methodology Allows For:

- Discrete shot lines through anatomy based on orientation of threat trajectory to personnel
- Projectile penetration mechanics through various anatomical structures
- Velocity retardation of threat through wound track
- Injury description by type, severity, and frequency
- In-depth description of operational effectiveness

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# Background

## Personnel Inputs- Injury (AIS/MAIS)

- ORCA utilizes the **Abbreviated Injury Scale**. AIS is an anatomically based, consensus-derived, international severity scoring system that classifies each injury by body region according to its relative importance on a 6-point ordinal scale
- MAIS - **Maximum Abbreviate Injury Score**

Severity	Injury Level	Example
1	Minor	Bruise
2	Moderate	Major Laceration / Simple Fracture
3	Serious	Femur Fracture
4	Severe	Serious Brain Injury
5	Critical	Cardiac Perforation
6	Maximal	Decapitation
9	Unknown	Only Region / Tissue Noted

5

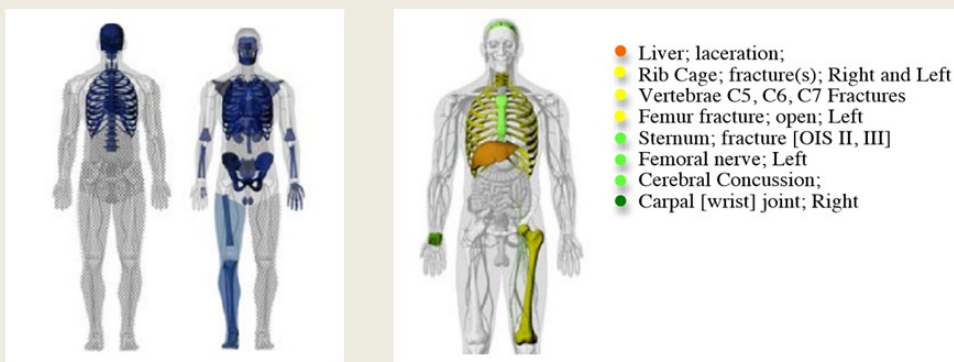
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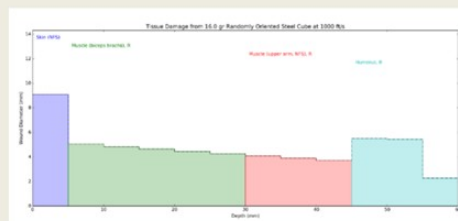
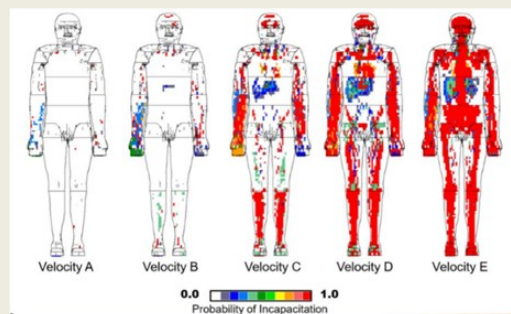
### Visual Anatomical Injury Descriptor – (Visual AID)

A web-based graphics tool enabling individuals to illustrate injury onto an anatomical figure and perform discovery operations by inspecting injury patterns using composite information



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## Why VR?!

[illegible]

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Methodology

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Methodology

Data Visualization/Geometry Optimization

```

ARL ORCA - Penetration Module (Version ORCA 4.33 Q2, 2016)
Fri Sep 16 11:45:40 2016

Single Shot Mode
Client ID: Default Single Shot Pen.
# Mass (grams): 16,000
# Striking Velocity (m/sec): 304,000
# Density (grams/cc): 7,800
# Shape Factor (dimensionless): 1,500
# Material: Steel
# Effective Diameter (mm): 7.051

Shotline Origin (mm): 305,000 215,000 1612,000
Azimuth (degrees): 0
Elevation (degrees): 0

Number of boxes hit: 1
Box hit order (increasing distance along shotline):
br[entry(m)] exit(m) d(mm) u(x,y,z)
12 -0,000 180,000 180,000 305,000 215,000 1612,000 0,000 -1,000 0,000

TID SEC ROW COL DISTANCE DEPTH DIAMETER SDO VOLUME VELOCITY
t 1 12 11 61 15,000 5,000 0,000 0,000 0,000 304,000 6 r
t 1 12 11 62 15,000 5,000 0,000 0,000 0,000 304,000 6 r
t 1 12 11 61 15,000 5,000 9,488 9,488 0,348 304,000 15 d
t 1 12 11 61 15,000 5,000 9,488 9,488 0,348 304,000 7 d
t 7 12 12 61 20,000 10,000 0,000 0,000 0,000 270,421 9 r
t 7 12 12 62 20,000 10,000 0,000 0,000 0,000 270,421 3 r
t 7 12 12 61 20,000 10,000 5,009 5,009 0,099 270,421 4 d
t 7 12 12 62 20,000 10,000 5,009 5,009 0,099 270,421 2 d
t 7 12 11 62 25,000 15,000 0,000 0,000 0,000 259,428 10 r
t 7 12 11 61 25,000 15,000 0,000 0,000 0,000 259,428 2 r
t 7 12 13 62 25,000 15,000 4,809 4,809 0,189 259,428 3 d
t 7 12 13 61 25,000 15,000 4,809 4,809 0,189 259,428 2 d

```

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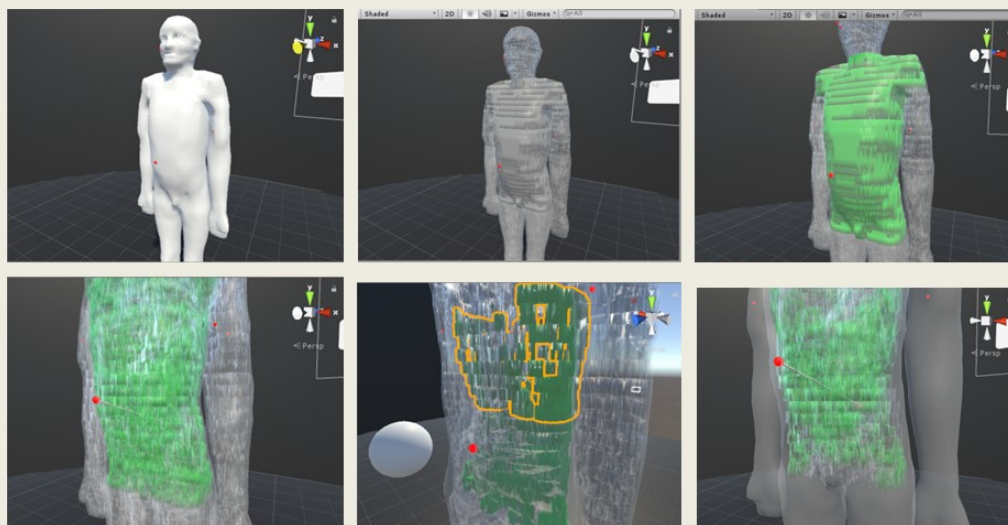
## Trajectory Visualization

Penetration plot of tissue damage from 1.6.0 gr steel cube and corresponding shot line geometry representing depth and diameter of tissue damage:



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## Tissue Visualization



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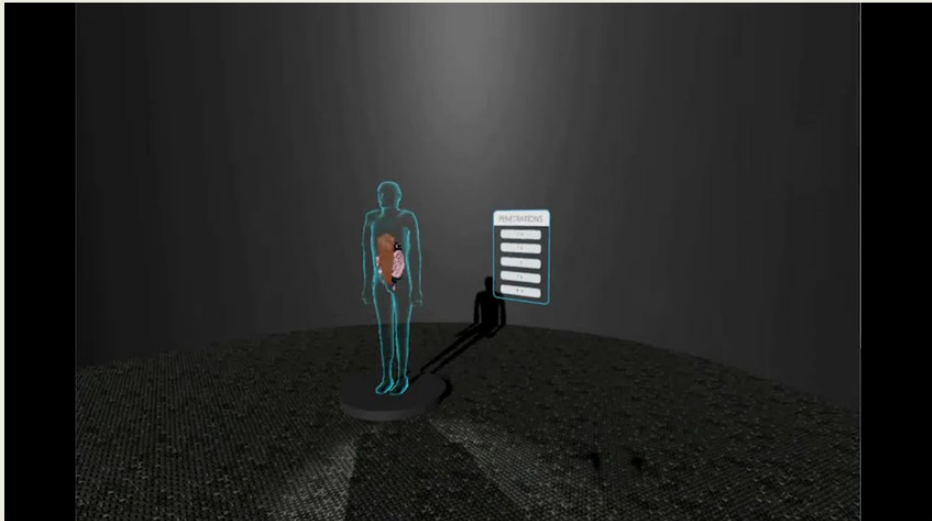
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# Methodology

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ANNUAL RESEARCH AND DEVELOPMENT REPORT

## Interactive Virtual Reality Example- Teleportation



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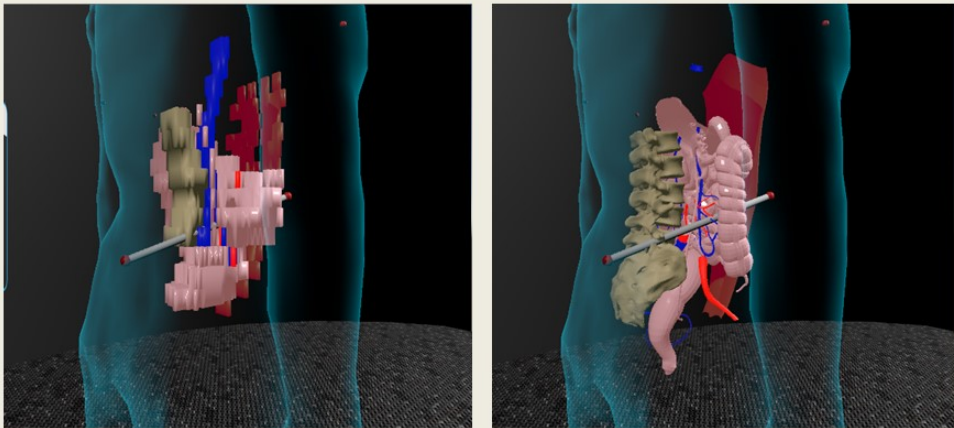
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# Results

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ANNUAL RESEARCH AND DEVELOPMENT REPORT

## ORCA vs. Visual AID

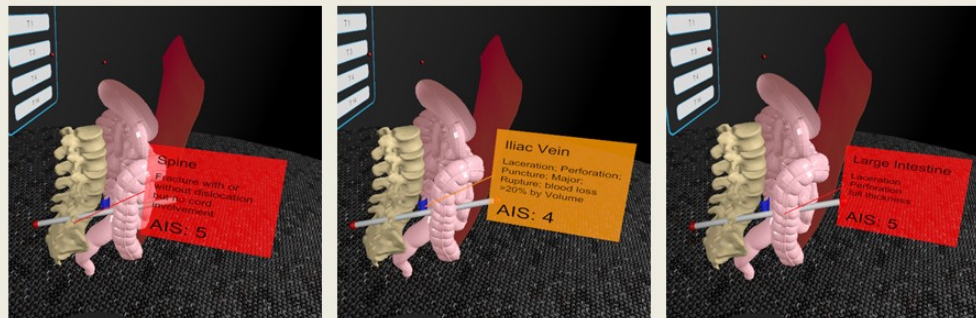


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## User Interface



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- User Note Taking/Image Saving
- Custom data importing
- Clipping plane
- Wound-track animation
- Co-operative design mode
- Population of models ( anthropometrics & postured)
- Context relevant environments (vehicle systems)





*A special thank you:*

Autumn Kulaga

Timothy Myers

Lee Butler

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2 DIR ARL  
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(PDF) RDRL WML B  
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